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RADIATION HAZARDS OF PRIMARY COSMIC PARTICLES

by

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HOLLOMAN AIR FORCE BASE
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RADIATION HAZARDS OF PRIMARY COSMIC PARTICLES

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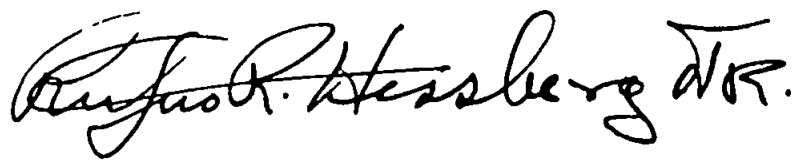
ABSTRACT

In 1954, Task 78500, Radiation Hazards of Primary Cosmic Particles, was included within the framework of Project 7851, Human Factors of Space Flight. From 1954 until termination of the project in 1958, most of the cosmic radiation studies conducted by the Aeromedical Field Laboratory were included in Task 78500. This report presents a summary of the studies conducted under Task 78500 and the results obtained from these studies.

PUBLICATION REVIEW

This Technical Report has been reviewed and is hereby approved for publication.

FOR THE COMMANDER:



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RADIATION HAZARDS OF PRIMARY COSMIC PARTICLES

I. INTRODUCTION

Many new problems were ushered in by the discovery in 1948 of heavy cosmic ray primaries. Their properties and characteristics were essentially unknown and their possible biological effects posed a serious potential hazard to space flight. Knowledge concerning these primary cosmic particles has increased tremendously since their discovery, but much is yet to be learned. Specifically, very little is known of the biological effects of the heavy primary cosmic particles; the flights reviewed in this report were designed to gain as much information on this facet of the whole problem as possible. Since it is believed that the potential hazard to humans in space flight centers upon the heavy nuclei component of cosmic radiation, this field of research must be thoroughly explored (Ref. 14). The balloon flights conducted by the Aeromedical Field Laboratory provide one mode of research into the radiobiological effects of primary cosmic radiation, but continued efforts in this field are necessary if man is to successfully and safely participate in space flight.

To date, no means are available in the laboratory to produce heavy particles with energies such as those possessed by the primary cosmic particles in space. Heavy ion linear accelerators are capable of producing medium weight nuclei of the neon-carbon range with energies within an order of magnitude of cosmic ray primaries. Utilizing these accelerators, experiments could be devised and studies should be made prior to final experimentation in space conditions.

II. PRIMARY COSMIC RADIATION

Primary cosmic radiation is composed of nuclei of elements ranging from hydrogen through iron. When these primary particles interact with the atmosphere, they produce gamma rays, beta particles, positrons, μ and Π mesons, protons, neutrons, neutrinos, and alpha particles (Ref. 21). This radiation, produced as a result of primary cosmic particle interaction with the atmosphere, is known as secondary cosmic radiation.

The studies encompassed in this task were primarily designed to determine the biological effects of the primary cosmic particles and more specifically, the heavy primary particles (nuclei ≥ 6). This primary radiation traverses space and arrives at the edge of our atmosphere essentially unchanged from its original form. Upon entering the atmosphere, secondary radiation is produced through ionization of, and

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Released by author, 22 April 1959.

collision with, atmospheric molecules and atoms. This interaction is so complete that no primary cosmic radiation is present below approximately 70,000 feet.

The origin of the primary particles reaching our atmosphere is generally accepted to be within our own galaxy. Further, within the galaxy, the origin is believed to be supernovae which have occurred therein, and the millions of stars within our galaxy.

Now, we must orient our position on earth within the galaxy of almost imperceptible proportions. The earth is one of nine planets orbiting around the sun; the sun is one of millions of stars within one of several arms and a nucleus comprising the galaxy of approximately 100,000 light years diameter. The sun's distance from earth averages 93,000,000 miles, while other stars are many light years distant from the earth.

Keeping the above parameters in mind, we will divide the origin of cosmic radiation into two categories. One originates from our sun (solar origin), and the other originates from within our galaxy (galactic origin), excluding the sun. The sun can only be considered an average star and it may seem strange to consider it as one source of primary particles and group the millions of other stars into one other category. This is not as unproportional as it may initially seem, when consideration is given to the earth's proximity to the sun compared to the earth's distance from other stars. For example, if Alpha Centauri, our nearest star excluding the sun, produces cosmic radiation equal to that produced by the sun, the amount of this radiation reaching earth is only 5.6×10^{-12} of that produced by the sun. Other stars at greater distances would contribute even less. Under these circumstances, it is not difficult to grasp the great importance of solar radiation.

First, let us consider the primary cosmic radiation produced by the sun. True, this radiation is probably no more than that produced by the other stars, but as mentioned earlier, the relative nearness of the earth to the sun greatly increases the effect of this radiation on earth. In addition to the production of primary particles by the sun, it greatly affects the galactic radiation reaching earth. This effect by the sun on galactic radiation is accomplished by giant magnetic clouds released by the sun. These magnetic regions in our solar system modulate that radiation entering from the extra-solar region (Ref. 25).

Another important consideration is the spectral composition of solar radiation versus galactic radiation during strong solar flares. Cosmic ray intensity data following the most recent and spectacular solar flare (February 1956) showed a twenty-fold normal value at sea level in many places all over the earth. Analysis of these intensity data indicates the particle intensity of this additional radiation produced in the

solar flare increases much more sharply toward low energies than in normal cosmic radiation (fig. 1). The intensity beyond our atmosphere of particles below one BEV of energy during such flares has not been measured, but may be assumed to be many times above the normal intensity (Ref. 27).

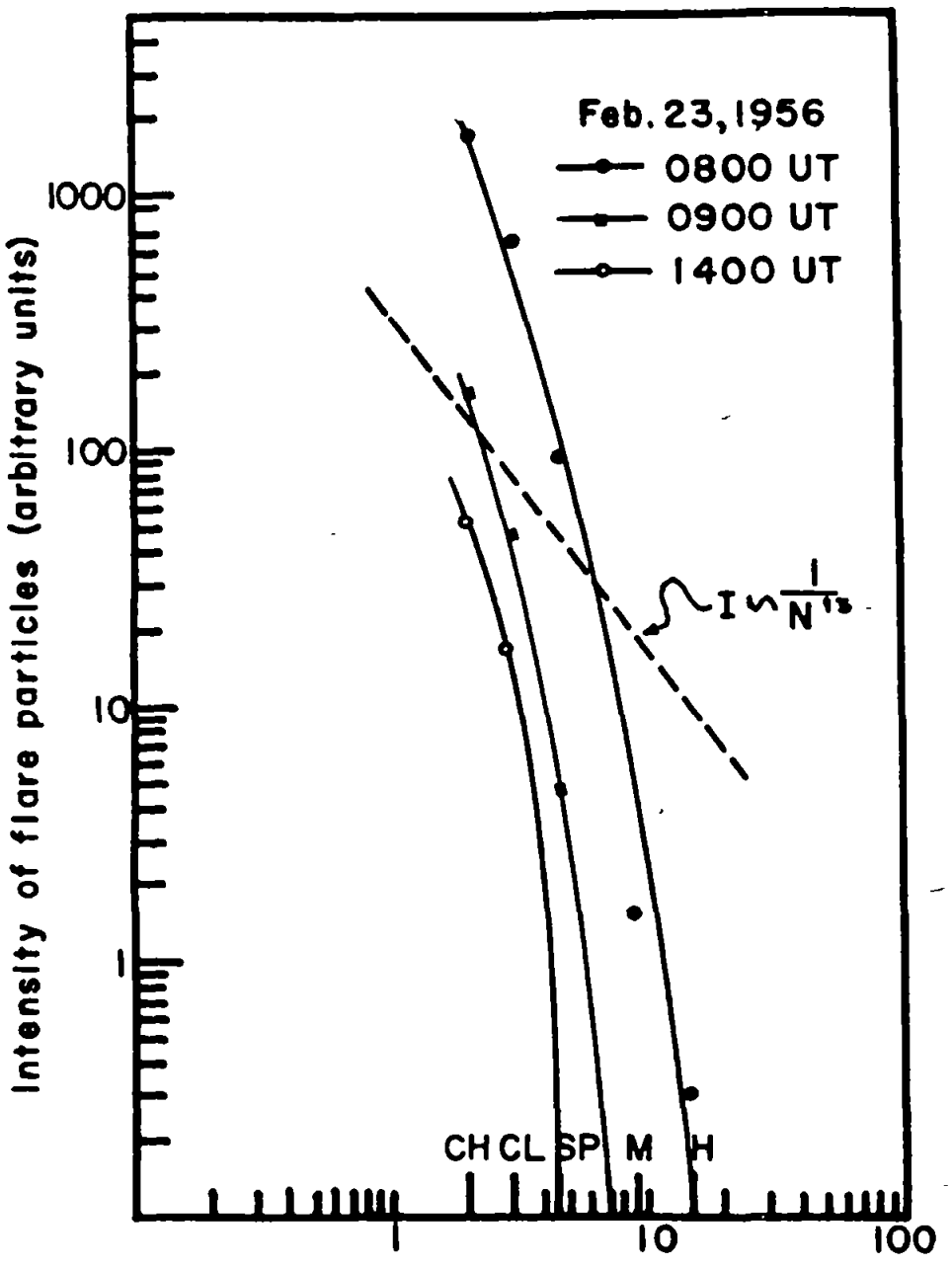
Galactic radiation reaching our atmosphere is overshadowed by solar radiation because of the relative distances involved. Primary radiation of galactic origin is ever present at the border of our atmosphere, but fluctuations in the primary flux and spectrum found in the regions of earth are primarily attributed to solar origin.

The particle energy when entering the atmosphere determines largely whether the particle will terminate completely by ionization (thin-down) or as a nuclear collision with atmospheric atoms and molecules. Incident particles under one BEV per nucleon usually terminate by thin-down, and as the particle energy increases, the likelihood of termination by thin-down decreases.

From thin-down frequencies observed in nuclear emulsions (fig. 2 and 3), Yagoda (Ref. 33) has determined the frequency that would have occurred in tissue. Extrapolation to the top of the atmosphere indicates that approximately 28 medium and heavy nuclei would terminate as thin-downs in each cubic centimeter of tissue per day. Beyond the effect of the earth's shadow, this value should almost double.

The terminal portion of the particle terminating by ionization alone has an extremely high specific ionization, and it is the terminal ionization peak which is believed to be the most biologically significant (Ref. 14).

The depth to which primary particles penetrate prior to termination is nearly the same in tissue, air, or other materials when the penetration is expressed in gm/cm^2. This depth of penetration varies between the different primary nuclei becoming progressively less for a given energy as the atomic number increases (fig. 4). When a heavy particle terminates by thin-down, it produces a unique radiation pattern. As the particle approaches termination, the Rate of Energy Loss (REL) gradually increases until, just before termination, it reaches an abrupt ionization peak. Based on the REL and the known biological danger of alpha particles (fig. 5), Schaefer (Ref. 14 and 18) calculated thin-down hit patterns using the criterion of 10,000 ion pairs per micron of tissue traversed. Nuclei of the C N O group experience this REL for a distance of nearly 100 microns; iron nuclei for nearly a millimeter. The biological experiments discussed in this report used the above criterion of a hit in determining the primary cosmic particle exposure.



The spectrum of cosmic-ray particles produced by the flare. (23 Feb. 1956). The normal cosmic-ray spectrum is shown as a dashed line but with arbitrary intensity $N \sim pc/ze$

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FIGURE 1.

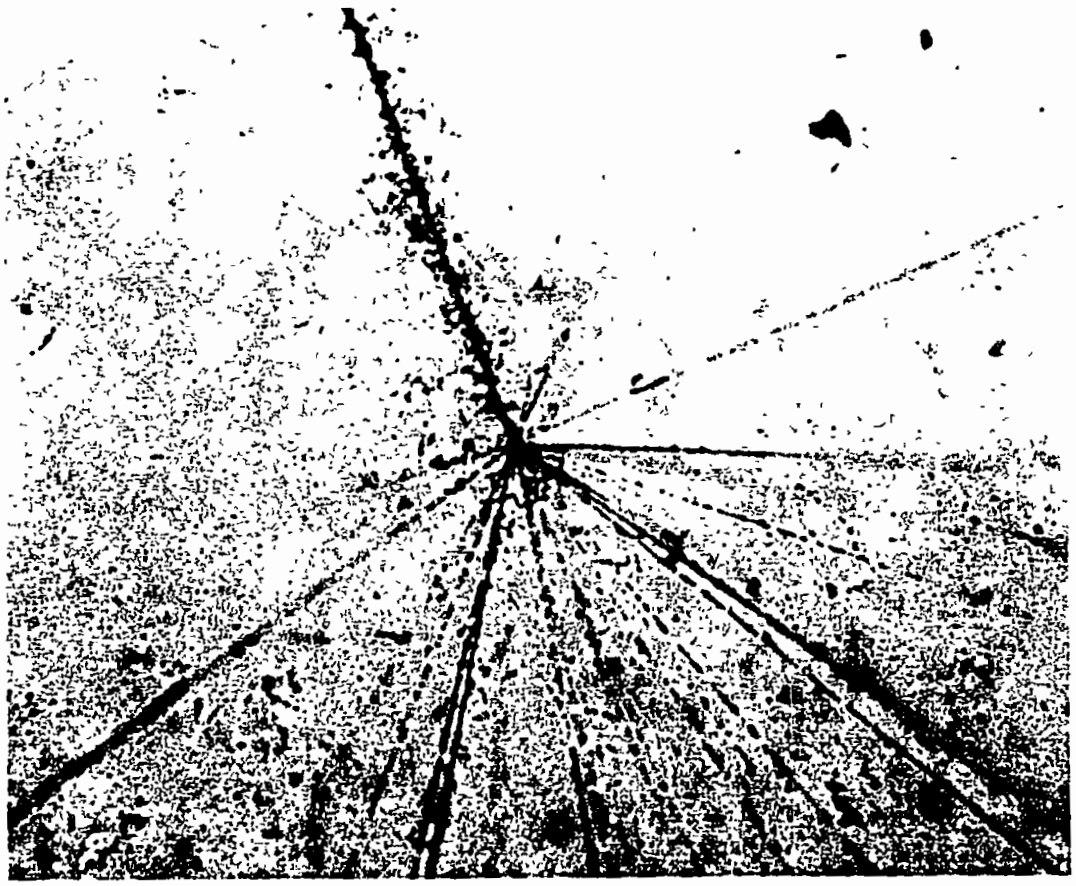


FIGURE 2. Photograph of a High Energy Primary Cosmic Particle Colliding with an Absorber Nucleus, Producing Many Secondary Fragments (Star Formation).

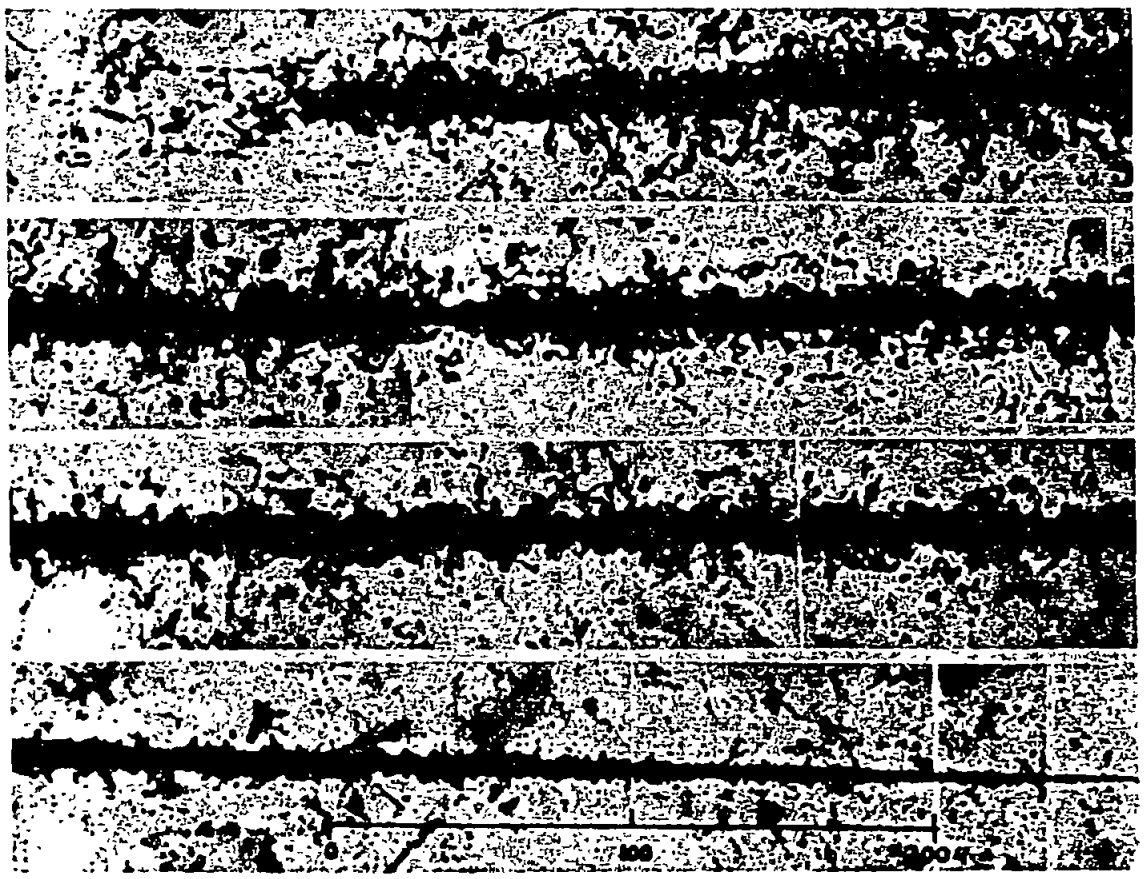


FIGURE 3. Photograph of the Terminal High Specific Ionization Portion of the Path of a Low Energy Primary Cosmic Particle (Thin-Down). The particle enters the emulsion top left and terminates bottom right.

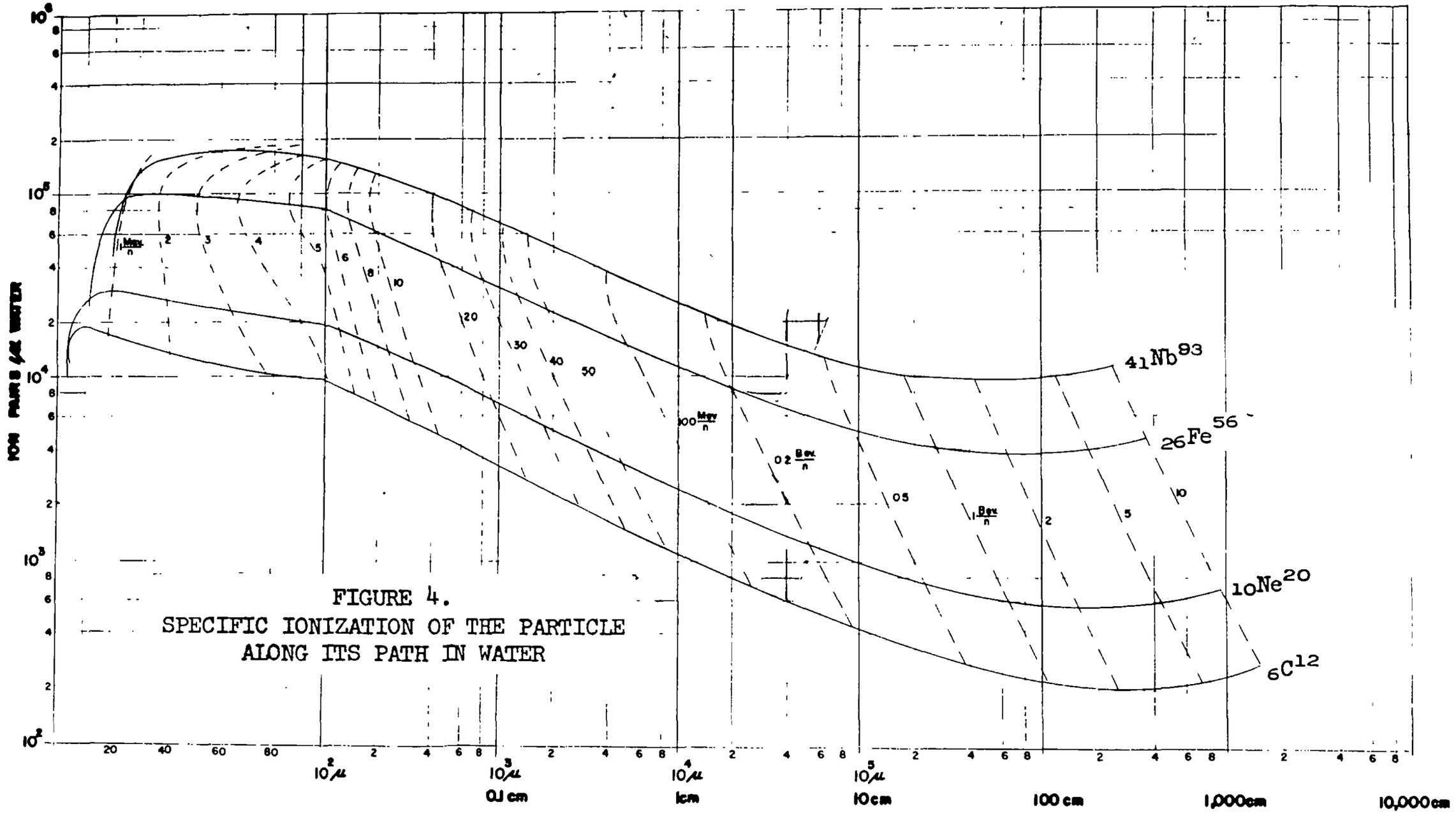
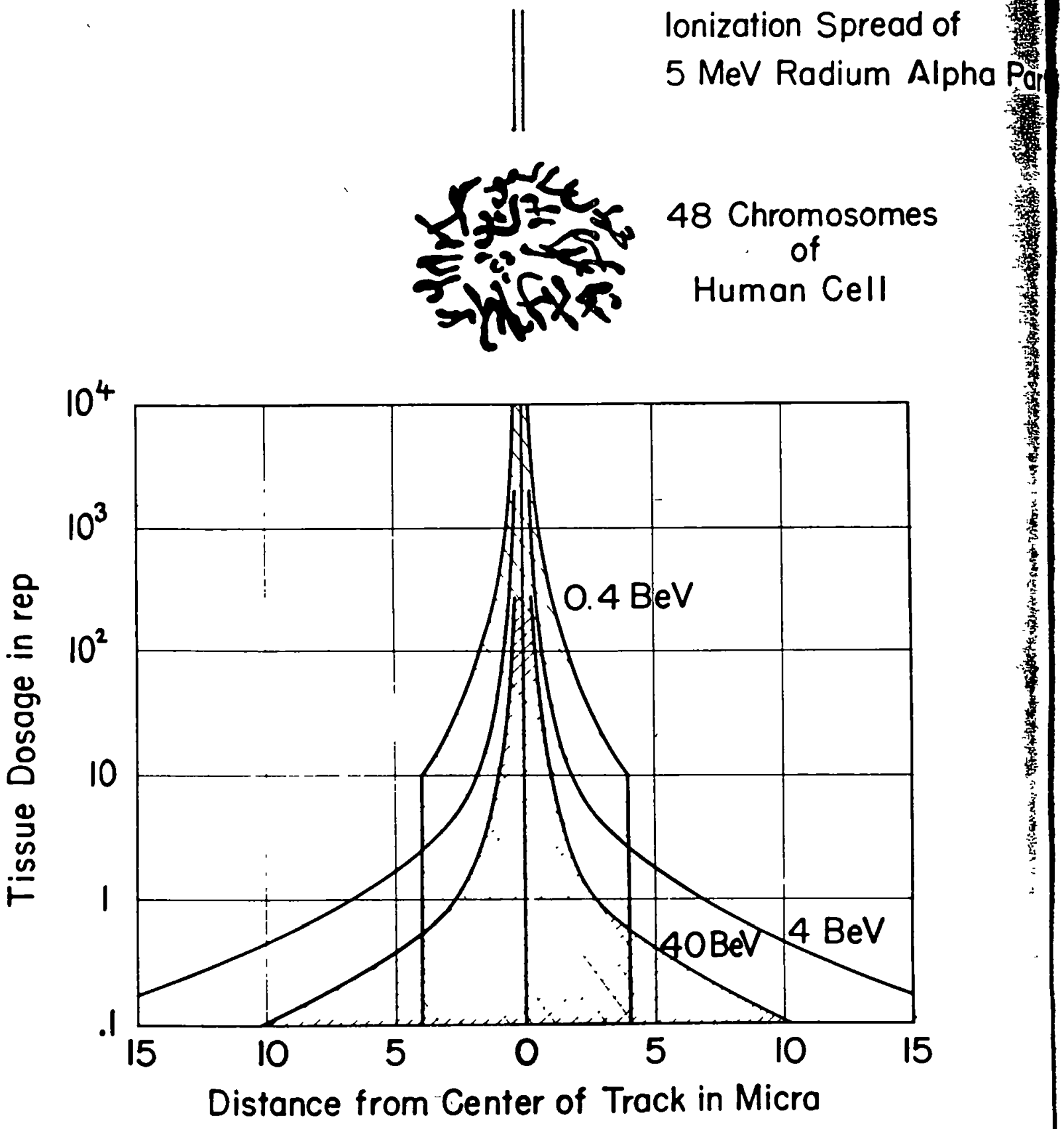


FIGURE 4.
SPECIFIC IONIZATION OF THE PARTICLE
ALONG ITS PATH IN WATER



RADIAL SPREAD OF TISSUE IONIZATION DOSAGE ABOUT HEAVY NUCLEUS TRACK OF

FIGURE 5.

The origin of the primary cosmic particles is generally assumed to be of solar and galactic sources. The mechanisms of acceleration and modulation of incoming particles have not been thoroughly explored.

A great increase in particle intensity following solar flares has been observed. It is known that the low energy particles increase much more than particles of higher energy. The extent of this increase has been determined for particles above approximately 1 BEV in energy. Below this energy no data are available, but the slope of the curve at 1 BEV suggests a possible hundred- or even a thousand-fold increase for lower energies. Since particles of 0.1 BEV to 1 BEV are considered most hazardous biologically, this gap in our knowledge is of utmost importance. Studies of primary particles have been limited almost exclusively to particles with energies above 1 BEV and to light-weight particles (protons - alpha particles). This is a natural occurrence since measurements of lower energy particles are extremely difficult, and because light-weight particles are much more abundant. The relative abundance of primary particles in space is approximately 80 to 85 percent protons, 14 to 17 percent alpha particles, and approximately 1 percent heavier elements distributed in roughly the same proportions as their cosmic abundances (Ref. 26). Even these figures are based on relatively little sampling and are based on periods of solar quiescence. Whether this relative abundance is applicable during periods of great solar activity has not been established.

It must be emphasized that the particles assumed to be of greatest biological significance are medium to heavy particles (C-Fe), with relatively low energies. As stated above, little or no data are available on particles with these characteristics. The seriousness of this void cannot be overemphasized when radiobiological effects of primary cosmic radiation are considered.

The biological effects of primary cosmic radiation are not completely understood and studies concerning these biological effects are made extremely difficult because of (1) inability to simulate heavy ($Z \geq 6$) primaries in laboratories and (2) variability in primary radiation exposure to specimens during high altitude flights. High altitude balloon flights have been utilized chiefly as the vehicle for obtaining biological exposures in regions of primary cosmic particles. During these flights and between balloon flights, variation in exposure to the primary particles results from changes in balloon altitudes, geomagnetic trajectories, solar activity, attenuation of particles by the capsule and components, and variation in particle intensity. To intelligently assess biological damage caused by the cosmic primaries, the radiation exposure to the biological specimens must be known. This must include charge and energy data for all incident primaries. To date, this radiation exposure has been assessed from neutron data, nuclear track plates, and theoretical calculations, all of which have

inherent shortcomings. With the future development of mechanical counters and other detection devices, this difficulty of assessing exposure should be greatly reduced, thereby allowing better evaluation of biological damage.

III. METHODS

Since the studies conducted under Task 78500 were aimed primarily at determining the biological effects of cosmic ray primaries and because this radiation cannot be adequately simulated in laboratories, it was necessary to elevate the biological test systems to high altitudes. These high altitude flights are necessary in order to obtain exposure to primary particles before their interaction with our atmosphere. Further, because of the influence of the earth's magnetic field on incoming low energy heavy primaries (fig. 6), it was necessary to launch the flights above 50 degrees north geomagnetic latitude (Ref. 7). This was necessary in order to obtain biological exposure to the low energy heavy primaries which are responsible for the most biological damage during thin-down. To obtain quantitative exposure, the biological specimens must remain at altitude for several hours. To meet these requirements, stratosphere balloons were determined to be the only feasible flight vehicles (see fig. 7).

The flights discussed in this report occurred in several series. Following the last flight from Holloman AFB, New Mexico, on 16 December 1953, covered in HADC-TR-54-16, six control flights were launched from Holloman in the spring of 1954. These were termed control flights because at the latitude from which launch occurred, no primary thin-downs occur even though other environmental conditions are the same as for test flights from northern latitudes. A northern series of flights was launched from Saulte Sainte Marie, Michigan, during the summer of 1954 (Winzen Research, Inc.) and six more control flights from Holloman (HAFB Balloon Branch) were launched from 12 October 1954 to 17 June 1955. The last northern series was launched from South St. Paul, Minnesota, and International Falls, Minnesota, from July to September 1955 (Winzen Research, Inc.). Three control flights from Holloman AFB during November 1955 to April 1956 were the last successful animal balloon flights launched for the Aeromedical Field Laboratory.

A flight series was planned for the summer of 1958 using a new five million cubic foot balloon to obtain higher altitudes than were routinely attained on previous flights. Three attempts by Winzen Research to launch this huge balloon failed and subsequently the contract was cancelled.

Biological specimens exposed to primary cosmic radiation at altitudes of 90,000 to 120,000 feet required a carefully controlled sealed

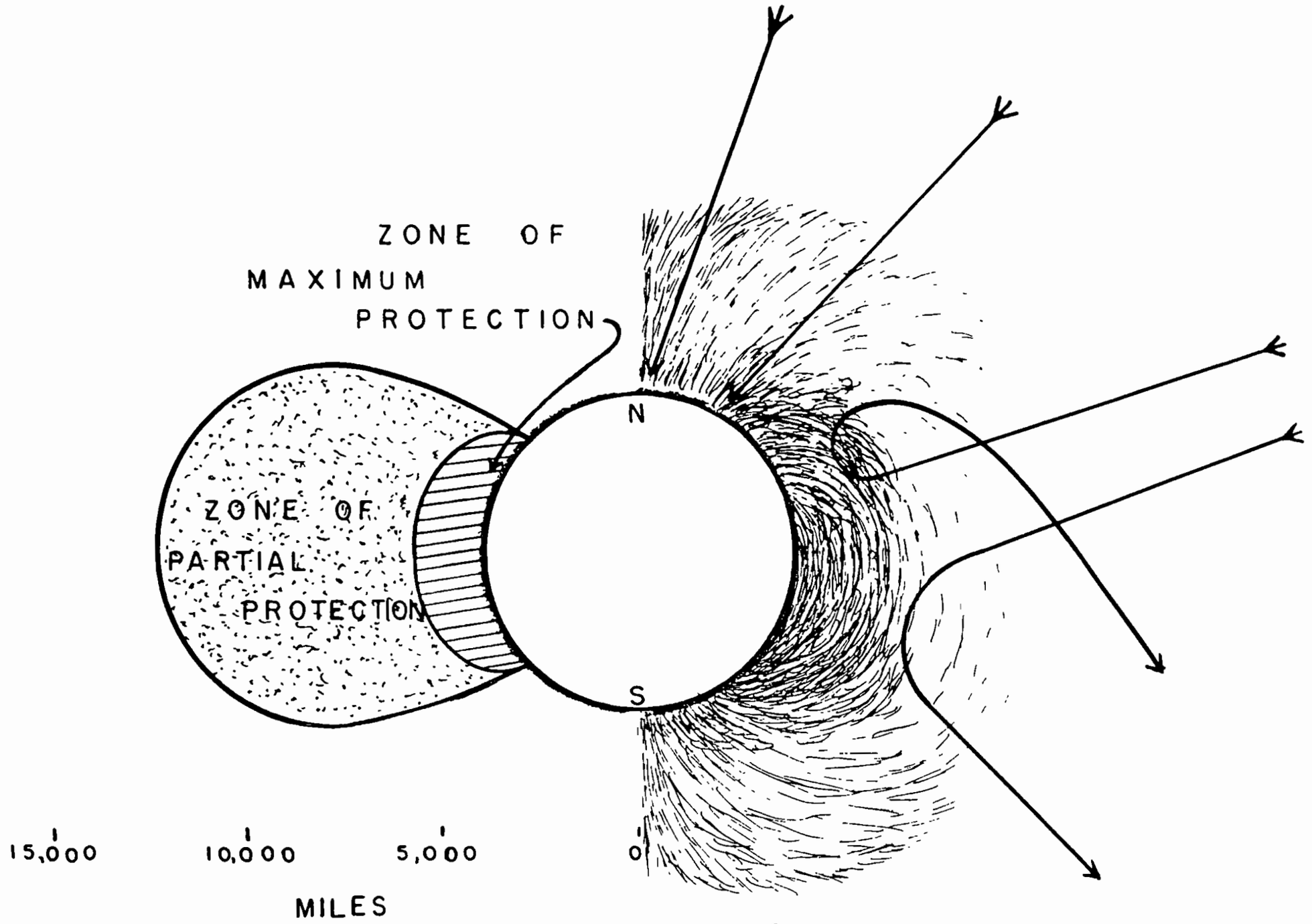


FIGURE 6.

Schematic Diagram Showing Effects of Earth's Magnetic Field
on Incoming Cosmic Ray Primaries

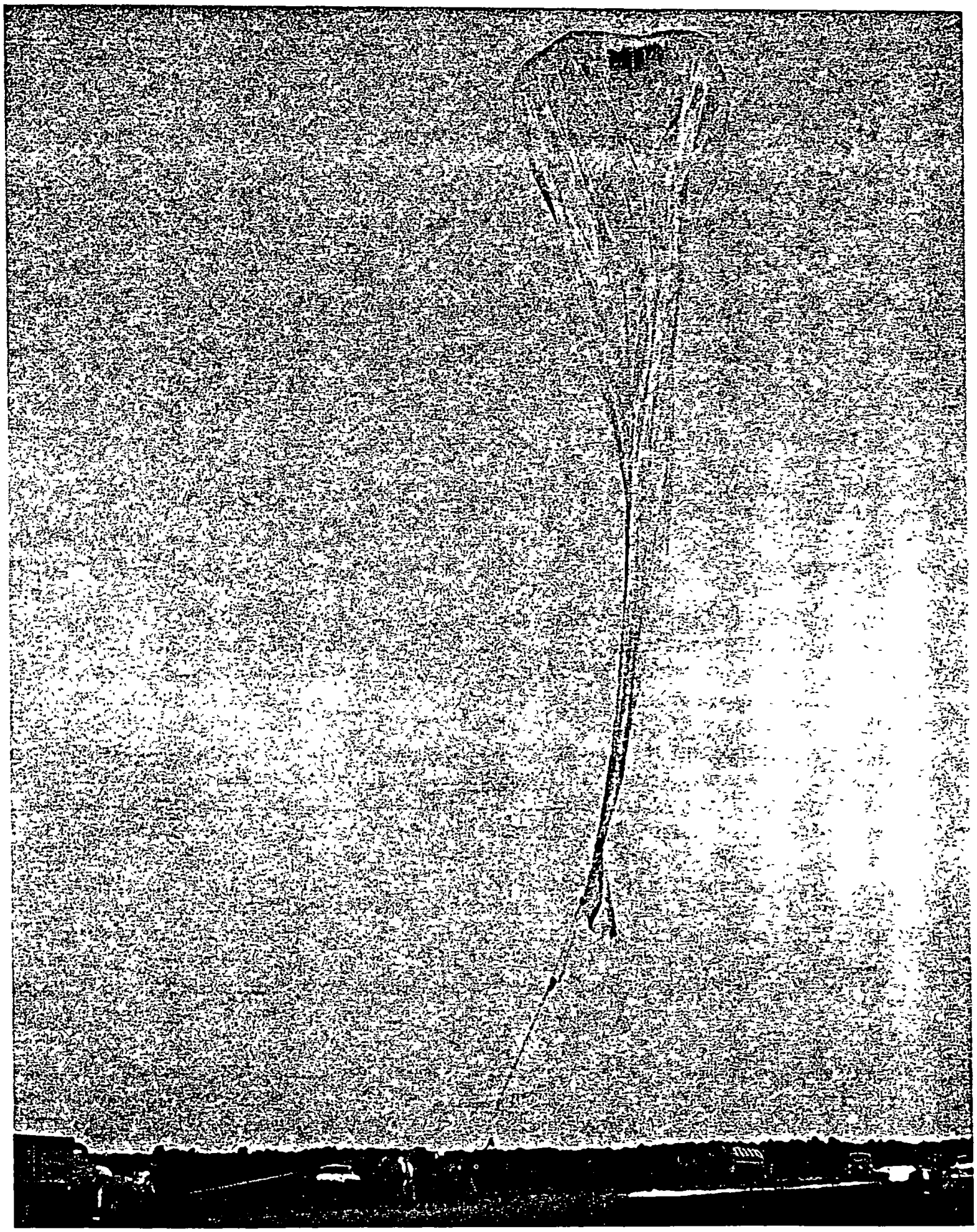


FIGURE 7. Launch of a Stratosphere Balloon Flight for Exposure of Biological Specimens to Primary Cosmic Radiation.

cabin environment (Ref. 15). Oxygen must be provided and carbon dioxide must be removed; the inside capsule temperature and relative humidity must be controlled.

The early capsules were assembled from two spun aluminum hemispheres. The capsules used on the 1954 flights were 76 cm in diameter, while the capsules used in 1955 were 58 cm in diameter (see fig. 8) (Ref. 20). Miniaturization of capsule instrumentation allowed this decrease in size (fig. 9). A fiberglas capsule was fabricated of approximately the same weight as the aluminum type capsule; however, closure of the two hemispheres was greatly simplified by using a quick sealing clamp in lieu of the many bolts necessary on the aluminum types (fig. 10).

Oxygen was provided from metal cylinders strapped outside the capsule (fig. 11). It was supplied to the capsule by means of a demand valve to maintain approximately atmospheric pressure. Carbon dioxide was removed from the capsule by blowing the air through a tube filled with soda lime. Low weight silver-cell type storage batteries were used to supply power for the blowers and to operate a unit which recorded capsule temperature and pressure.

The temperature was maintained by providing sufficient external insulation so that the body heat of the animals kept the capsule warm at night. Excess heat which accumulated during the day was removed by operation of a water can cooler (fig. 12). This cooler was thermostatically controlled to maintain an even temperature. The cooling unit is based on the principle that the lower the pressure, the lower the boiling point of water. At 112,000 feet, the boiling point approaches the freezing temperature for water.

Two important factors were discovered during the 1954 flights and subsequent modifications were made in the cooling system for the 1955 flights: (1) the size of the vent line for transmission of water vapor from the cooler-can is quite critical if the system is to be effective; the 1954 flights used a 1/8-inch vent line and conversion to a 3/8-inch vent line in 1955 proved to be much more effective, and (2) in 1954, the cooler-can had fins only on the exterior of the can. To transfer heat more efficiently fins were also added inside the can in 1955. These modifications made the cooling system very satisfactory.

Relative humidity within the capsule was kept within tolerable limits in two ways. Excess moisture condensed on cool surfaces, i.e., the water can cooler, and especially at night on the cool internal capsule surfaces. In addition, the soda lime removed some moisture from the air (see fig. 13 and 14).

A smoked disc barothermograph was used to record internal capsule temperature and pressure during the flight. In addition, a coded cylinder type barothermograph (fig. 15) was included for transmission of temperature and pressure data via the balloon radio.

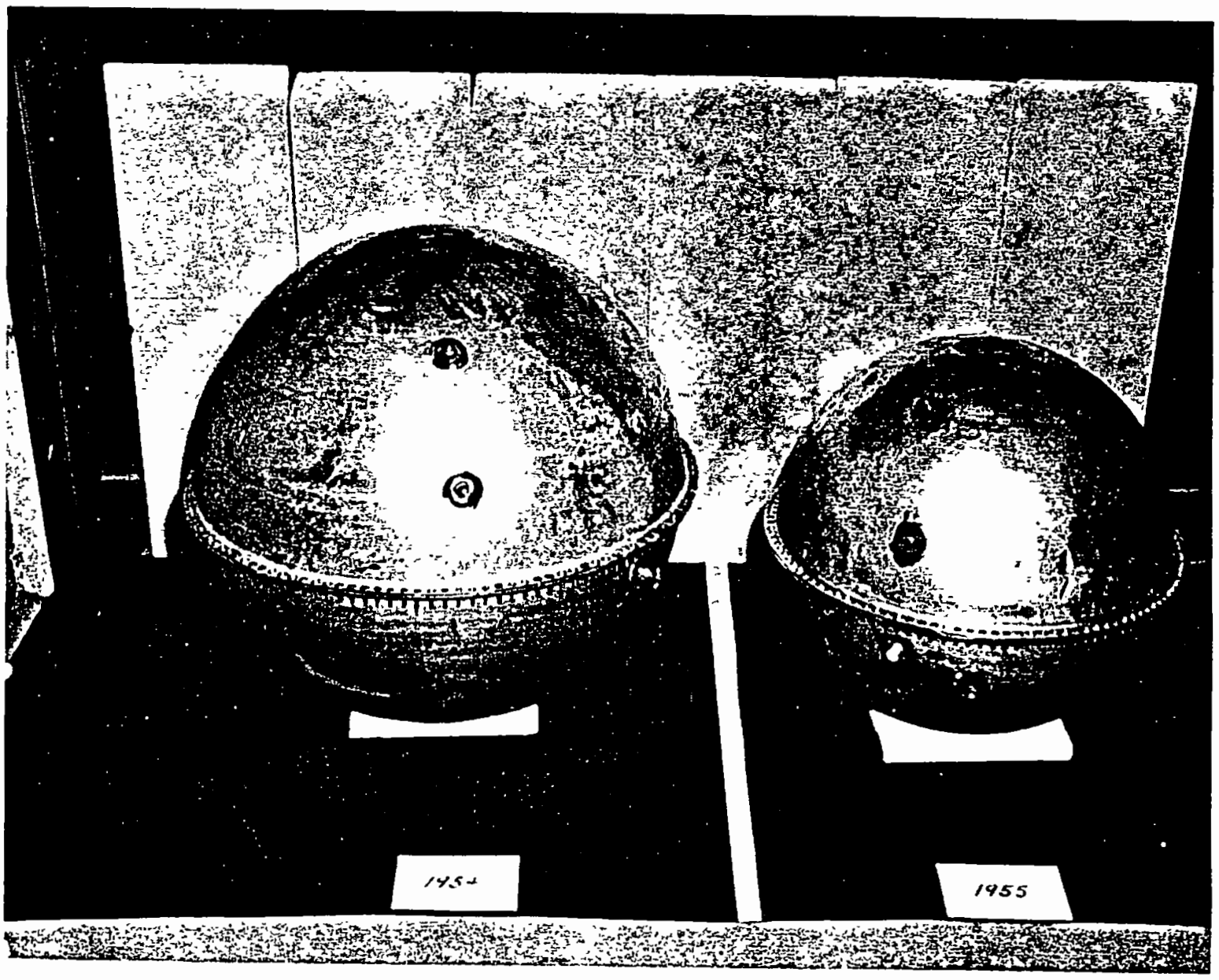


FIGURE 8. The Capsules Used in 1954 (left) and 1955 (right). Note difference in size.

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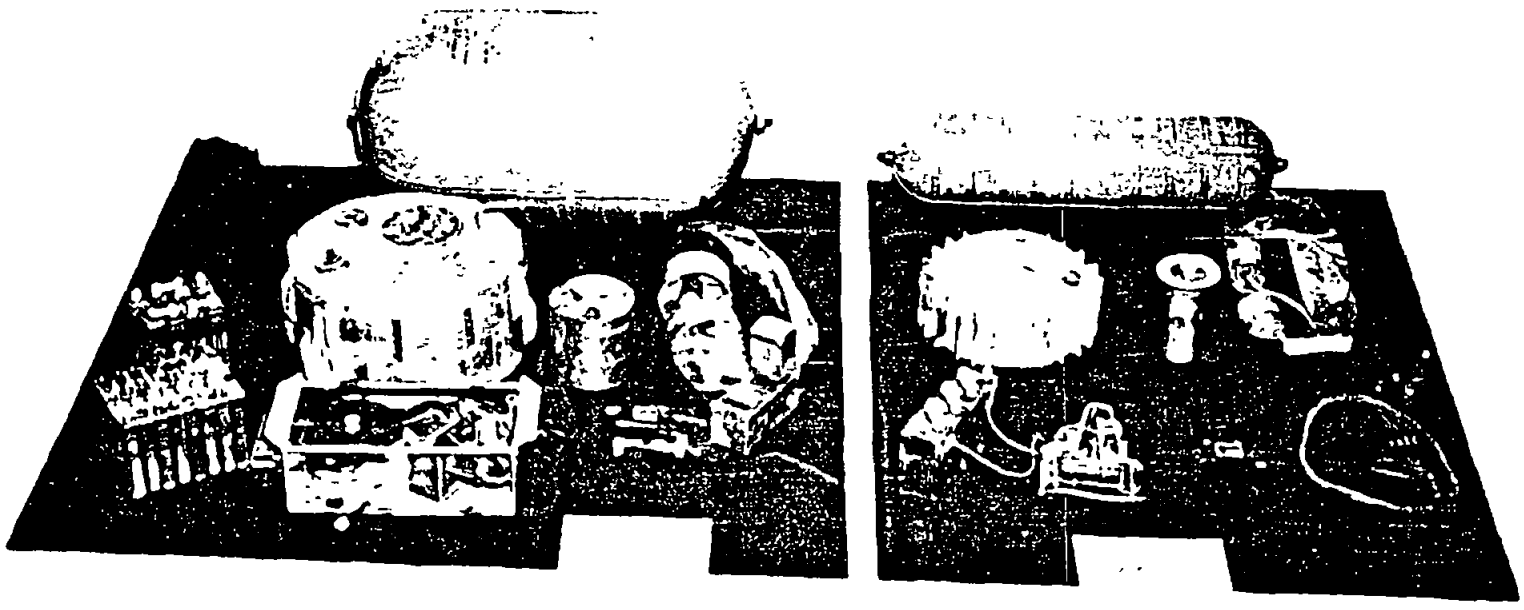

FIGURE 9. Photographs Showing for Comparison the Contents of the Animal Capsules Used in the 1954 (left) and 1955 (right) Flights. The oxygen cylinders are in the rear. In the center are, left to right, the water can coolers, cooling fans, and carbon dioxide absorber units. In the foreground are batteries, barothermographs and coders, demand oxygen regulators, and electrical junction boxes.

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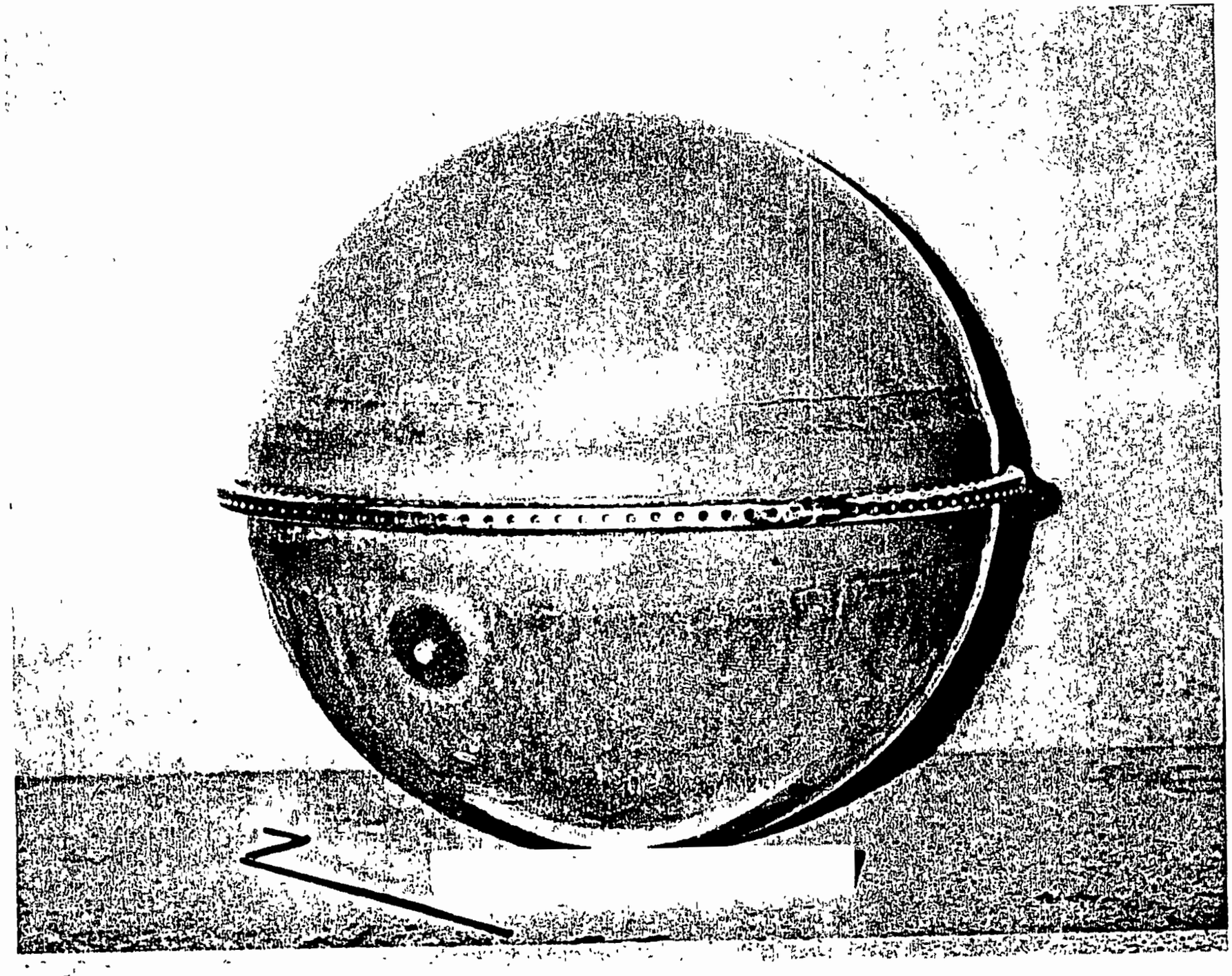

FIGURE 10. Fiberglas Capsule. Note quick sealing type clamp.

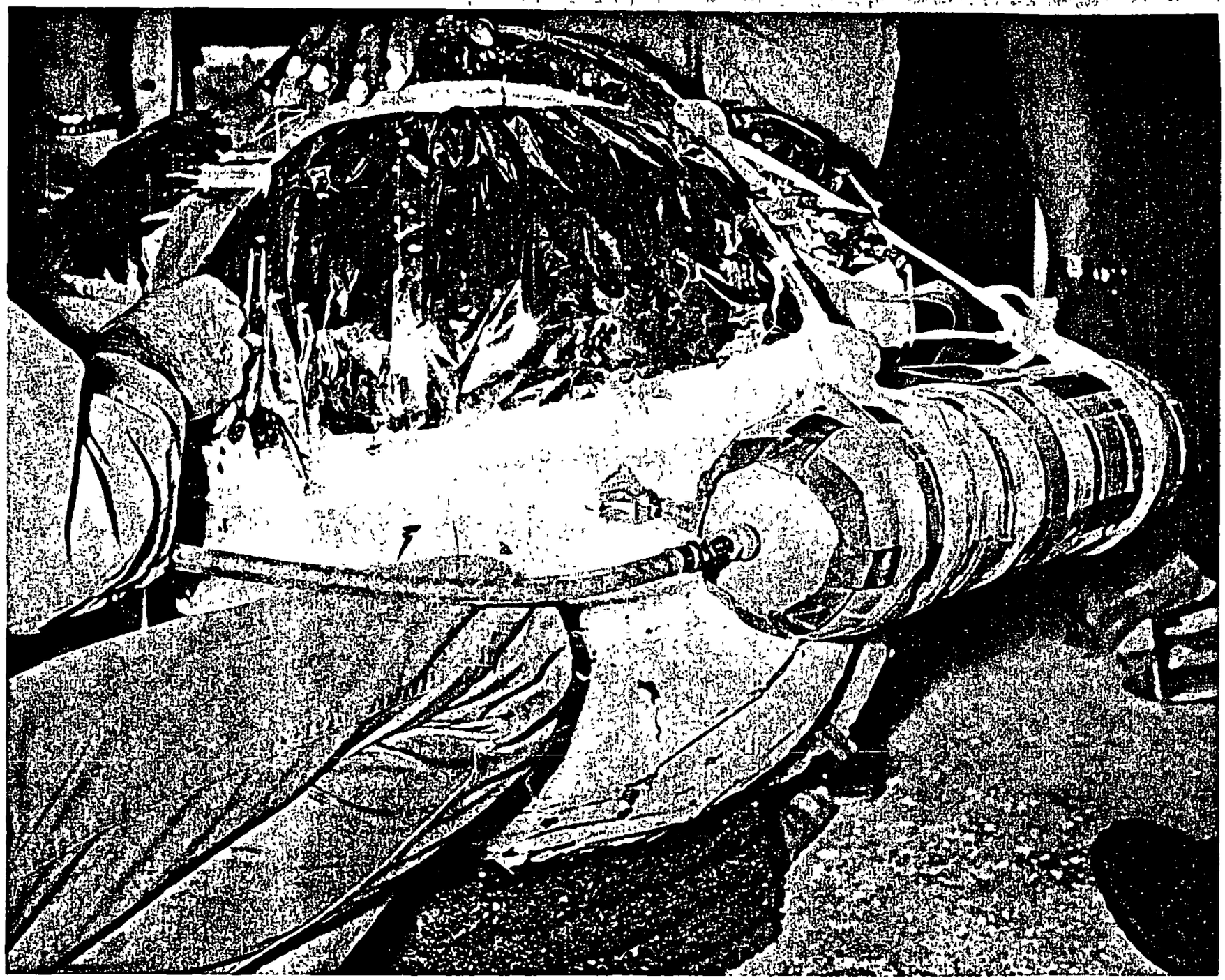

FIGURE 11. Assembled Capsule Ready for Flight. Capsule is covered with insulation, with oxygen cylinders attached.

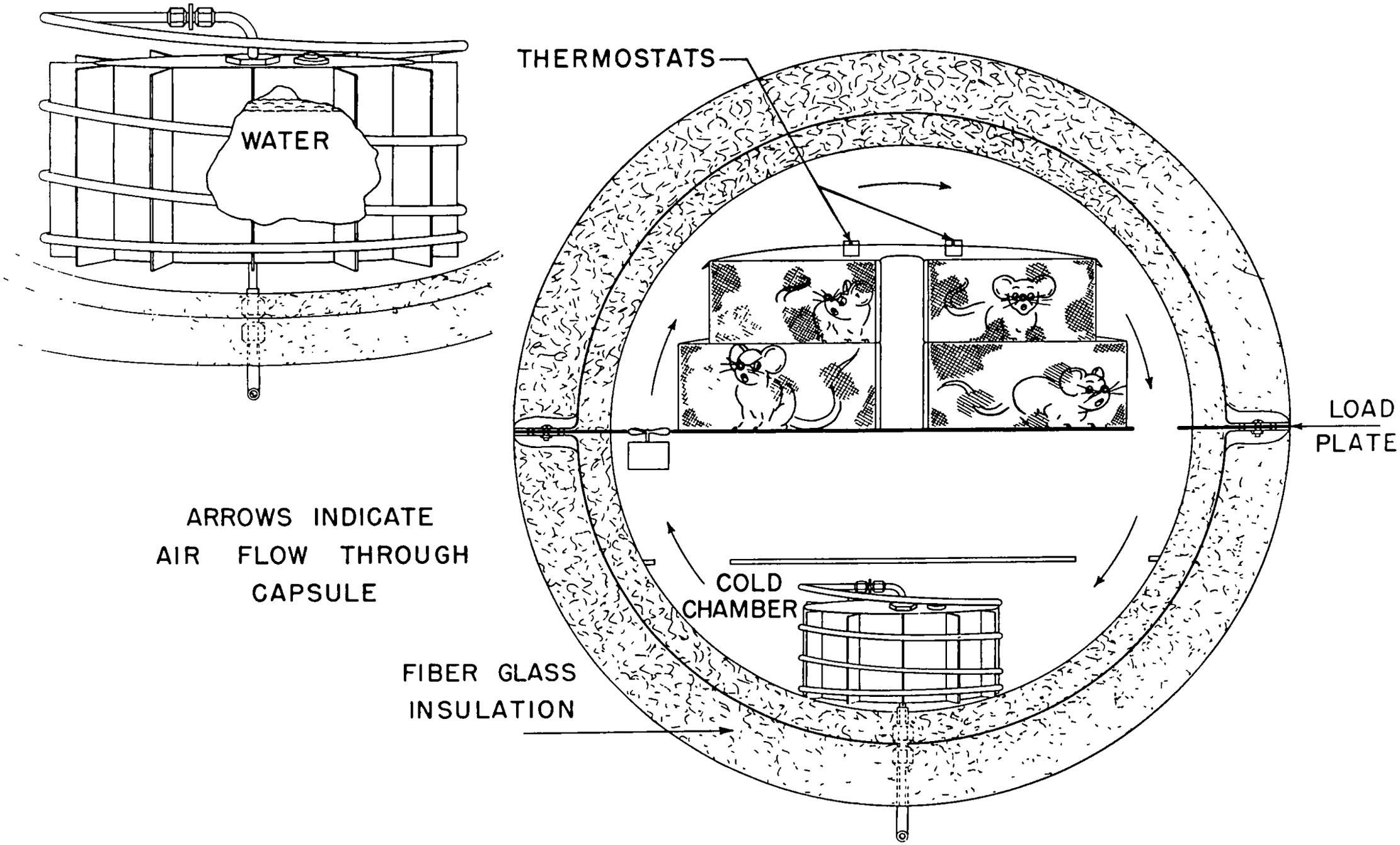

FIGURE 12. Aeromed Capsule Cooling Unit.

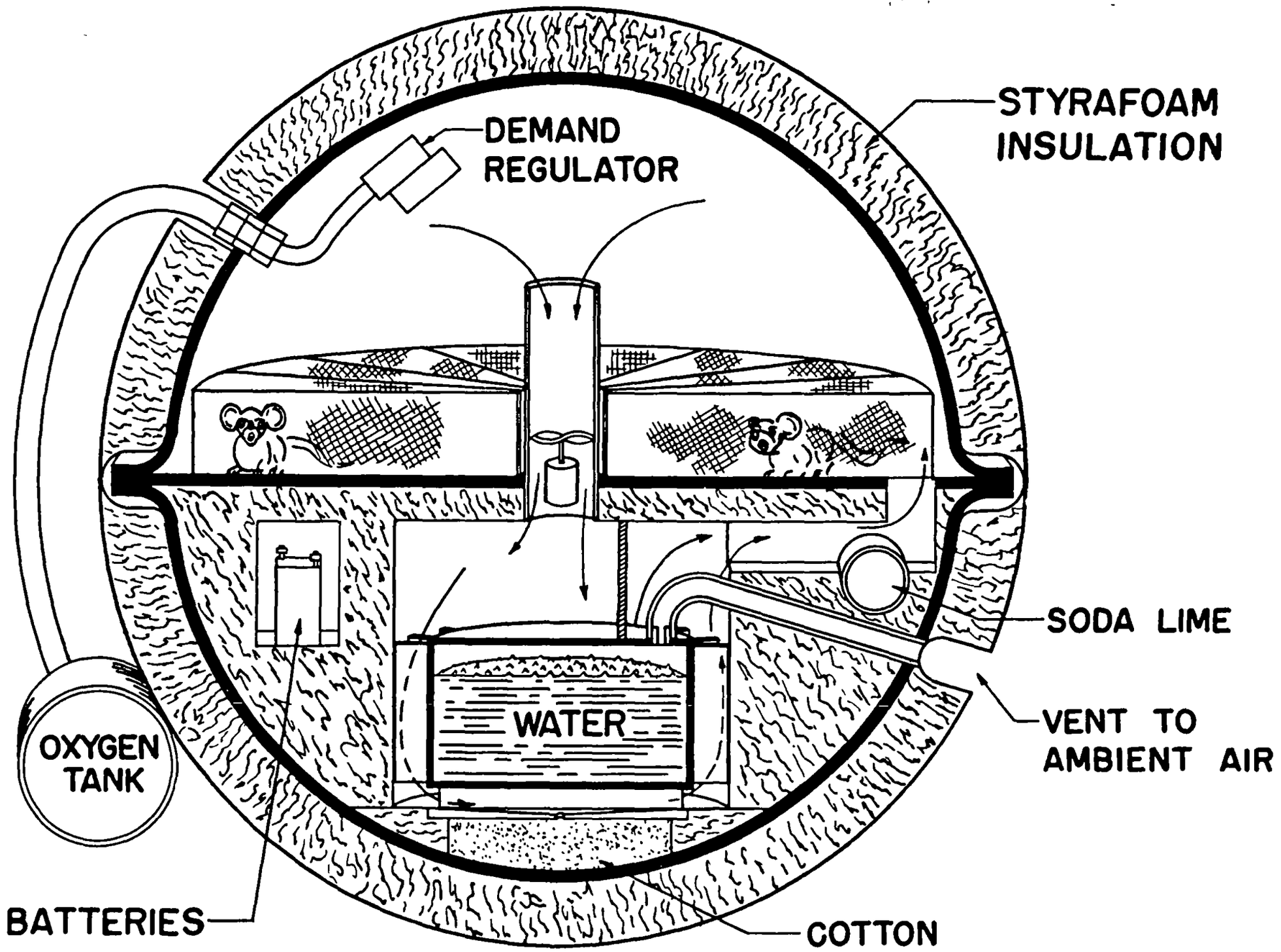

FIGURE 13. Schematic of Capsule Cross Section

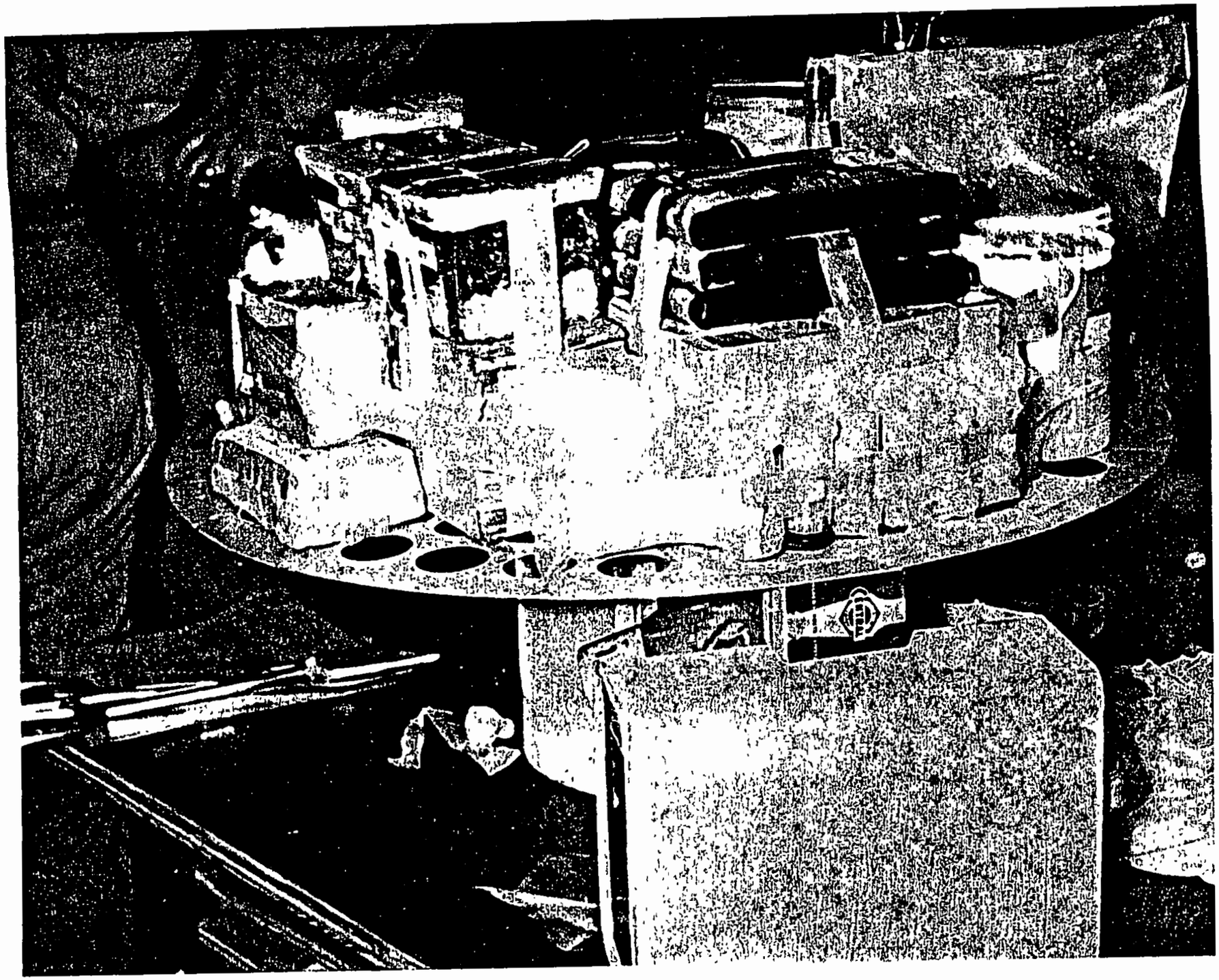

FIGURE 14. Biological Specimens in Place on Load Plate Prior to Being Placed Within the Capsule.

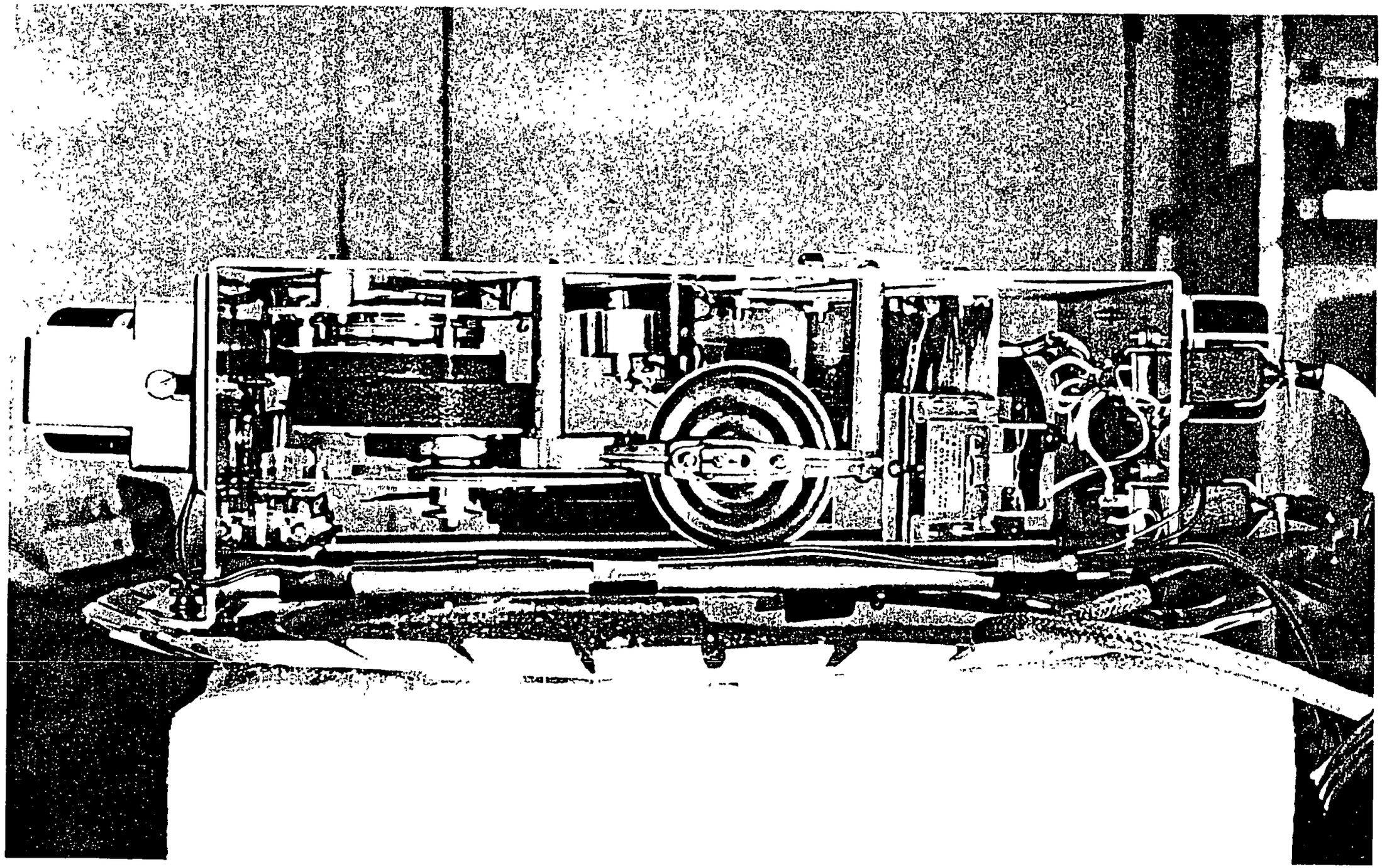

FIGURE 15. Barothermograph Unit. Left portion is the recording device, right portion is the keying apparatus for telemetering of temperature and pressure data.

IV. EXPERIMENTAL APPROACH

There have been two approaches to the problem of designing experiments to assess the biological effects of cosmic radiation. One is to employ a system which will demonstrate the direct effect of a single hit. The second is a system which will indirectly reflect the damage caused by one or more hits. The former is of primary significance for two reasons. First, calculations of hit probabilities as shown in Table I (Ref. 15) indicate that specimens sufficiently small to be flown in significant numbers are not exposed to enough radiation by nuclei with suspected biological effects to cause general damage which could be detected by the indirect approach. The second reason is the fact that the ultimate resolution of the nature of the biological damage caused by cosmic radiation is dependent on a correlation between the specific type of biological damage and the physical characteristics of the incident particle. This means that not only must systems be utilized which can reflect the effect of a single hit, but the system must also be amenable to monitoring that will permit identification of the physical characteristics of the particle involved.

Only two experiments were conducted using the indirect approach. One was a monkey performance study and the other a mouse longevity study.

A. Monkey Performance and Mouse Longevity Studies

The monkey performance study consisted of post-flight examination of two monkeys which had spent 63 hours above 30 kilometers on two successive flights from Saulte Sainte Marie, Michigan. The animals were carefully examined on the following factors (Ref. 12):

1. Weight and general behavior.

2. Ability to perform tasks learned before exposure.

3. Ability to learn new tasks.

4. Gross neurological changes.

The mouse longevity study was performed by Dr. Irwin Lebish under the surveillance of Dr. Webb Haymaker, both of the Armed Forces Institute of Pathology. The study consisted of primary cosmic radiation exposure to White Swiss Bagg strain mice of both sexes, to determine its effect on longevity and breeding.

On 22 August 1955, 89 mice were placed within a pressurized capsule and elevated to an altitude of 109,000 feet by means of a polyethylene balloon. Total exposure above 105,000 feet was approximately 12 hours; above 80,000 feet, 22 hours. The capsule was quickly

TABLE I

COSMIC RAY HIT PROBABILITIES* IN BIOLOGICAL SPECIMENS
AT 55 DEGREES NORTH GEOMAGNETIC

Specimen	Sensitive Volume or Area Assumed	Alt	Penetrations per Hour			Total
			Number of Thin-Down Hits**			
			Iron Group	CNO Group	Total Z 7	Flux Z 7
Black Mouse Skin	10 cm^2	90M	.013	.006	.039	71
		95M	.022	.007	.062	85
		120M	.104	.001	.176	160
Monkey	3000 cc	90M	1.4	90	115	#
		95M	2.2	112	148	#
		120M	10.8	192	305	2414
Mouse Brain	0.5 cc	90M	0.01×10^{-2}	4×10^{-2}	5×10^{-2}	28×10^{-2}
		95M	0.1×10^{-2}	4×10^{-2}	6×10^{-2}	37×10^{-2}
		120M	0.8×10^{-2}	1×10^{-2}	6×10^{-2}	79×10^{-2}
Radish Seed or Mouse Eye	7.0 mm^2	90M	9×10^{-5}	5×10^{-5}	28×10^{-5}	0.5
		95M	16×10^{-5}	5×10^{-5}	44×10^{-5}	0.6
		120M	74×10^{-5}	0.7×10^{-5}	125×10^{-5}	1.1

* Calculations extrapolated from Schaefer.

** Defined by Schaefer

Figures available for the primary flux at the top of the atmosphere only.

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recovered and opened upon landing. Four animals were dead and the remainder were returned to their cages. The next day 52 control animals were placed within the same capsule and subjected to the same flight conditions on the ground, e.g., duration of flight, internal pressure, and temperature. One control mouse succumbed during this procedure. On 2 September 1955 the animals were returned to the Armed Forces Institute of Pathology in Washington, D. C., where they remained for the duration of the experiment. The last mouse died in July 1958, ending the study.

The remainder of the experiments was of the direct approach type and a brief discussion of each follows.

Throughout the period of cosmic radiation research conducted by the Aeromedical Field Laboratory, studies were made by various universities under Air Force contracts with the Aeromedical Field Laboratory. A list of these contracts with principal investigator and type of study performed is shown in Table II.

B. Study of Integument

Chase observed that four to six melanophores supply all the pigment for the hair growing from one follicle of a black mouse. These melanophores are highly radio-sensitive, non-regenerative, and are non-redundant. Evidence of the death of hair follicle pigment cells is multiplied a thousand-fold in the growth of a readily detected gray (non-pigmented) hair (Ref. 2 and 4). For these reasons, black mice are especially well suited for detecting cutaneous effects of primary cosmic particles (fig. 16).

Two types of cutaneous studies were accomplished. One consisted of exposing black mice to primary cosmic radiation and comparing the number of gray hairs post-flight to the control animals. The other study encompassed the above observation, but in addition attempted to identify the incident particles by means of nuclear emulsions attached to the mice.

Plastic tubing, plastic splints, and celastic jackets were used in attempts to secure nuclear track plates to mice. These techniques are described in detail by Steinmetz (Ref. 29).

C. Genetic Studies

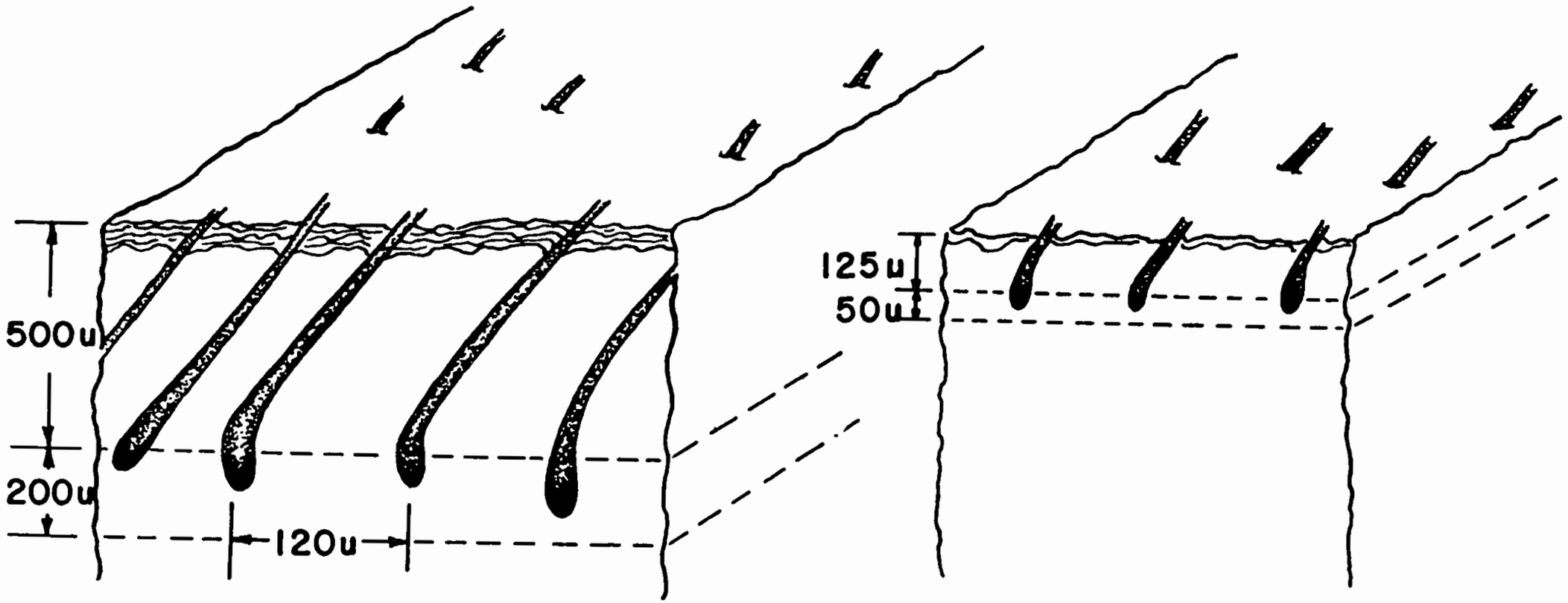
The genetic experiments conducted included as biological test specimens Drosophila melanogaster larvae and inseminated females, spores of Neurospora crassa, and corn and barley seeds. For each experiment, the material was divided into an exposed lot and a control lot at the launch site. For several experiments an additional control group was kept at the laboratory of the principal investigator.

TABLE II

LIST OF COSMIC RADIATION CONTRACTS

Contract Nr.	Contractor	Principle Investigator	Type of Study
AF29(600)1681	University of Texas	Dr. Wilson S. Stone	Genetic Effects of Primary Cosmic Radiation.
AF29(600)1477	Florida State University	Dr. A. Gib DeBusk	Genetic Effects of Primary Cosmic Radiation.
AF29(600)1476	Brown University	Dr. Herman B. Chase	Cutaneous Effects of Primary Cosmic Rad.
AF33(616)2085	Brown University	Dr. Herman B. Chase	Cutaneous Effects of Primary Cosmic Rad.
AF29(600)1723	Yale University	Dr. E. C. Pollard	Radiobiological Effects of Simulated Primary Cosmic Rad.
AF29(600)1759	University of Chicago		Cosmic Particle Counter.
	University of Minnesota	Dr. Berry Campbell	Neurological Effects of Primary Cosmic Radiation.
AF29(600)1333	University of California	Dr. Cornelius Tobias	Radiation Hazards of Space Flight.
AF33(616)2427	Winzen Research, Inc.		Provide Stratosphere Balloon Flights for Primary Cosmic Particle Exposure.
AF29(600)632	Winzen Research, Inc.		Provide Stratosphere Balloon Flights for Primary Cosmic Particle Exposure.

MOUSE HAIRS



GROWING RESTING

Schematic of follicle pattern observed over dorsum of C-57 black mice showing the separation and range of depth of follicles within the skin. (from data by Chase)

Stone (Ref. 30) has made genetic studies on Neurospora crassa using the heavy ion linear accelerator as the method of exposure. The exposures were accomplished at Berkeley, California, in collaboration with Tobias of the Donner Laboratories.

D. Neurocytological Studies

The susceptibility of brain cells to damage by primary cosmic radiation is of particular interest because of their crucial functional importance, low redundancy, and non-regenerative characteristic.

Campbell (Ref. 1), in 1953, conducted the first experiments to assess neurological damage caused by cosmic ray primaries. Since then several experiments have been done by Haymaker (Ref. 11) using various biological specimens.

The specimens were flown at altitude above geomagnetic latitude 55 degrees north for varying lengths of time. Following the flights, the animals were sacrificed, the brain tissue fixed and stained, and the tissue sectioned for microscopic examination. Then followed the laborious task of scanning thousands of slides in an effort to determine the path of damage caused by a primary particle. It soon became evident that a monitoring technique was necessary which would indicate the particle trajectory into the brain, thus reducing the large amounts of tissue which were to be examined. Only one flight utilizing the monitoring emulsions in the neurological studies was successfully flown. The flights planned for the summer of 1958 included monitored specimens for the neurological studies, but unfortunately these flights were never successfully carried out.

The monitoring method consisted of rigidly attaching by surgical means a track plate holder to the head of the specimens. Nuclear track plates were placed in the holder prior to flights. In this manner, particle paths observed in the emulsion can be projected to specific areas of the underlying brain.

E. Developmental Studies

Embryonic material was included in the biological experiments on the premise that small foci of damage resulting from primary particle hits would be greatly magnified as developmental defects with growth.

1. Fertilized chicken eggs were employed, but were not well suited to balloon experiments because of their sensitivity to accelerative forces, and because of the small percentage of the total volume which is embryonic tissue. Hit probability estimates which became available after the experiments had been attempted indicated that at least 100 eggs must be exposed to expect one heavy primary thin-down hit in the germinal tissue.

2. Pregnant mice were used in developmental experiments, but difficulties similar to those using chicken eggs were encountered. It is extremely difficult to ascertain early pregnancy in mice (first two weeks). Consequently, it was difficult to obtain a high percentage of pregnant mice at an early stage of gestation. As with chicken eggs, only a small percent of the total embryo will constitute centers of development sufficiently small that the loss of a few cells could be expected to cause macroscopic malformation.

3. Another experiment used radish seeds as the test specimen. Radish seeds were selected because of their resistance to extreme temperature and pressure variations, and because these seeds are easily germinated in the laboratory. The exposed seeds were flown for a total of 250 hours above 82,000 feet. Calculations indicated approximately 10 percent of these seeds should have experienced a thin-down hit.

4. Walton initiated an investigation of developmental aberrations among onion seeds, snapdragon seeds, and grasshopper eggs which were exposed to cosmic radiation. Examination of the onion seeds and snapdragon seeds included comparison of the sensitivity of "wet" and "dry" seeds in terms of percent germination. The onion seeds were also checked for length of hypocotyle and epicotyl unit time, and aceto-carmine smears to check for chromosomal aberrations. The exposed grasshopper eggs were compared with controls for rate of hatching, delayed hatching, and aberrant offspring.

5. Studies were accomplished by J. Eugster of Bern, Switzerland, to determine the effects of cosmic radiation on Artemia salina eggs (Ref. 9).

The criterion for damage was the hatchability of the eggs following exposure. The artemia eggs were placed on a checkered glass plate. Nuclear emulsions were placed on either side of the eggs to monitor the radiation exposure. Following high altitude exposures of the eggs, the nuclear emulsions were evaluated and those eggs hit as indicated by the emulsions were separated (Group 1). Those eggs on the flight not hit, as indicated by the emulsions, comprised another group (Group 2). A third group (Group 3) consisted of eggs similarly prepared but retained at the laboratory. Hatchability of the three groups was as follows:

Group 1 - 0.8 percent

Group 2 - 33 percent

Group 3 - 85-90 percent

All eggs survived the flight and even those receiving central hits (Group 1) proceeded into the early phase of embryonal development. Subsequent death of these eggs suggests lethal factors and chromosomal damage.

6. Egg albumin experiment-calculations indicate that the core of a heavy primary thin-down releases energy at a rate that should produce an effective temperature of between 500° and 1000°F. Since egg albumin is known to coagulate below 200°F, it was presumed that the path of a heavy primary thin-down might be marked by a residual thin filament of coagulated egg albumin.

Based on this thinking, Dr. Herman Yagoda, then of the National Institute of Health, now of the Air Force Cambridge Research Center, prepared a small plastic box of egg albumin monitored on both sides by nuclear track plates. After exposure on a MANHIGH test flight at 100,000 feet, the package of albumin was examined using dark field microscopy. Numerous filaments and stellate figures were observed in both the control and flight specimens, so that no positive conclusions could be drawn. Either a filtered albumin or a redissolved solution prepared free of natural filaments is indicated to conduct this experiment effectively. Based on similar concepts, the possibility of flying enucleated eyeballs for detecting tracks in the vitreous humor was considered. Observations of the coagulation characteristic of the vitreous humor in boiling water were discouraging. The strong lamellar structure consisting of alternate protein and sugar-rich layers made this approach appear impractical. Only the portion of the vitreous humor near the lens coagulated in boiling water. It would also require a difficult technique to examine the vitreous humor without disrupting its structure after flight.

F. Ophthalmological Studies

Two series of white mice were examined for possible lens damage following their exposures on balloon flights during the 1954 northern series.

Seventeen white mice accumulated an average of 16 hours per mouse above 30 kilometers and 49 white mice were exposed for an average of 33 hours per mouse above 30 kilometers.

These mice were examined post-flight by slit lamp microscopy at intervals of 14 days over a period of 3-1/2 months.

Thirty-nine control mice were flown from Holloman AFB (Geomagnetic latitude 41 degrees) and similarly examined.

G. Physical Monitoring Techniques

Calculations have been made which give the theoretical primary particle intensity at various altitudes and geomagnetic latitudes. To intelligently interpret the results from the biological studies accomplished, a more precise means of evaluating the actual exposure was needed.

During the period in which the experiments discussed in this report were conducted, it had not yet been determined that significant primary fluctuations occur from day to day. Consequently, precise particle monitoring of each flight was not emphasized. Neutron count data were considered satisfactory and although nuclear emulsions were included on many of the flights they did not serve as a monitoring method. Some emulsions were used to monitor specific specimens in an effort to localize hits; thereby allowing definite correlation between physical event and biological result.

Nuclear emulsions have three main shortcomings: (1) the length of exposure is limited to prevent over saturation of the emulsion, (2) extensive equipment is required for their development and scanning, and (3) several weeks are required for this development and scanning.

Because of the above mentioned disadvantages of nuclear emulsions, two other methods of monitoring the cosmic particles were tested.

One experiment for cosmic ray detection utilized triphenyl tetrozolium chloride incorporated in gelatin. This dye in an alkaline gelatin resulted in a yellow color. In an acid medium, the dye assumes a red color. High specific ionization by the cosmic particle in traversing the gelatin results in a pH change along the particle path. This pH change elicits a color change (yellow to red) along the path, thereby demarcating the particle hit. This color change is immediate and thus negates the long period of emulsion development. Only one experiment using this dye-gelatin preparation was accomplished, but a definite capability of cosmic ray detection by this technique was shown (Ref. 8).

The other method of monitoring which was tested by this laboratory was the use of phospholuminescent glass. This glass contains silver activated ions (Ag^+), and upon radiation the affected silver ions are reduced to the neutral atoms (Ag^o). The neutral atoms, when viewed with light of the ultraviolet wavelength, emit a characteristic fluorescent light. The basic idea of the experiment assumed that ionization by the cosmic particle in traversing the plate of photoluminescent glass would reduce the silver ions, and then upon observation with the proper light, the cosmic ray paths could be distinguished in the

glass. Again, only one exposure of such glass was accomplished, and this was on a flight from Holloman AFB, New Mexico, geomagnetic latitude 41 degrees. Upon examination, no paths or hits were seen; however, further experimentation must be conducted before this method can be discarded as unsatisfactory.

Neither a nuclear track plate developing facility nor trained personnel to operate such a facility have been available at Holloman AFB throughout the flights conducted by the Aeromedical Field Laboratory.

Complete monitoring of each flight is necessary if biological data are to be interpreted intelligently. If nuclear emulsions are used as the monitoring method, a track plate developing facility and the associated personnel must be available to the laboratory conducting the experiments. Efforts were being made toward obtaining such a facility when the cosmic radiation activities were terminated.

V. LIST OF BALLOON FLIGHTS

From the following list of flights it will be noted that the flights occurred in groups or series. The flights from northern latitudes (Michigan and Minnesota) served as exposure flights for the biological specimens (Ref. 28), while flights from Holloman AFB, New Mexico (southern latitude), provided control flights for specimens as well as opportunities to devise and evaluate new flight components and procedures. Flights 54 to 60 provided important capsule temperature data (Ref. 22).

AMFL FLIGHT 40

a. Balloon Type: 72.8-foot, 1.5 mil Winzen

b. Payload: Instrumentation, 50 pounds

c. Launch Date: 11 February 1954

Time: 1430 MST

Place: Holloman AFB, New Mexico

Type: Covered wagon

AMFL FLIGHT 41

This flight was designed to fly two dogs for 30 hours to check effectiveness of NYU capsule.

a. Balloon Type: 90-foot, 2 mil Winzen

b. Payload: One NYU capsule - 143 pounds total

c. Launch Date: 23 February 1954

Time: 1045 MST

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: The balloon ascended to approximately 60,000 feet and cut-down was attempted 1-1/2 hours after launch because of bad weather. Cut-down mechanism failed and aircraft tracking followed the balloon over Sheffield, Texas, but was lost during the night. The package was reported found the next day (24 February 1954) near El Dorado, Texas, and recovered promptly. Post-mortem examination revealed that the animals survived until shortly before recovery.

AMFL FLIGHT 42

This flight was designed to test high wind launch technique (shroud type inflation).

a. Balloon Type: 72.8-foot, 1.5 mil Winzen

b. Payload: Instrumentation, 120 pounds

c. Launch Date: 5 March 1954

Time: 1435 MST

Place: Holloman AFB, New Mexico

Type: Shroud type inflation

d. Flight Data: The balloon ascended to approximately 97,000 feet on 6 March and instruments reported it down near Kermit, Texas, from where recovery was promptly instituted. All instrumentation was recovered in excellent condition.

AMFL FLIGHT 43

This flight was designed for a 30-hour dog flight to test capsule heat and CO_2 and O_2 control.

a. Balloon Type: 90-foot, 2 mil Winzen

b. Payload: 225 pounds total

Instrumentation: 80 pounds

Capsule and Specimens: 145 pounds

c. Launch Date: 12 March 1954

Time: 0802 MST

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: The balloon ascended to approximately 75,000 feet and headed east at approximately 45 mph. Tracking was initiated with a C-47 aircraft and proceeded to Perrin AFB, Texas, where balloon radio signals discontinued. There was no report that the balloon had been found, so the tracking crew returned to Holloman AFB. On 21 March 1954, Winzen Research, Inc., received a letter from Mr. J. D. Weaner of Pattonville, Texas, stating that the balloon had landed on his property. All specimens had perished because of the delay in recovery.

AMFL FLIGHT 44

This flight was designed for testing capsule temperature control for 35 hours at 95,000 feet and as a control exposure for AFIP mice and Dr. Herman Chase's mice. Track plates and specimens for genetic controls were also on the flight.

a. Balloon Type: 116-foot, 2 mil Winzen

b. Payload: Capsule and Contents, 140 pounds

c. Launch Date: 24 June 1954

Time: 0730

Place: Holloman AFB, New Mexico

Type: Cap hold-down vertical technique

d. Flight Data: During launch a gust of wind caught the balloon and rolled one-half of cap over the balloon so that when the hold-down lines ran up over the balloon a large hole was torn in the polyethylene.

AMFL FLIGHT 45

This flight was designed to test AMFL capsule for temperature control at 97,000 feet for 35 hours, and instrument effectiveness and compatibility; also, to serve as exposure flight for AFIP mice, Dr. Chase's mice, and Dr. Stone's genetic specimens. A track plate monitoring system on cats was also tested.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Capsule and contents 132 pounds

c. Launch Date: 7 July 1954

Time: 0522

Place: Fleming Field, Minnesota

Type: Launch arms

d. Flight Data: Launch was very successful, but a capsule pressure leak detected on the balloon ascent necessitated cut-down at 79,000 feet. Recovery of the capsule was at 1030 on 7 July 1954, approximately 100 miles south of Fleming Field, Minnesota. All biological specimens were recovered in good physical condition.

AMFL FLIGHT 46

This flight was designed to provide primary cosmic radiation exposure for biological specimens.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Total load weight 730.5 pounds

Capsule contents:
3 monkeys
111 white mice
31 black mice
Radish seeds
Neurospora genetic samples
Track plates

c. Launch Date: 15 July 1954

Time: 0555 EST

Place: Saulte Sainte Marie, Michigan

Type: Launch arms

d. Flight Data: The balloon ascended at an average rate of 442 fpm and attained a maximum altitude of 96,750 feet. The balloon maintained an altitude above 82,000 feet for approximately 37 hours. The trajectory of the flight remained above 54.5 degrees north geomagnetic latitude. The load was released automatically by the cut-down timers at 1805 EST, 16 July 1954. The load was found and opened promptly by tracking personnel. Most of the animals survived the flight satisfactorily.

AMFL FLIGHT 47

This flight was designed for primary cosmic radiation exposure to biological specimens.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Total load weight 802.5 pounds

Capsule contents:
2 monkeys
94 white mice
26 black mice
Radish seeds
Neurospora genetic samples
Track plates

c. Launch Date: 18 July 1954

Time: 0522 EST

Place: Saulte Sainte Marie, Michigan

Type: Launch arms

d. Flight Data: The balloon ascended to its maximum altitude of 94,300 feet by 0800 EST, 18 July 1954, and remained above 92,000 feet for 34.5 hours. The trajectory of the flight was above 56 degrees north geomagnetic latitude. Because of beacon power supply difficulties, command ballast and separation were not available. Automatic ballast and separation functioned adequately and at 1835 EST, 19 July 1954, the load was released automatically. The package landed at 1910 EST and was recovered by the ground party at 2100 EST. Most of the animals did not survive this flight.

AMFL FLIGHT 48

This flight was also designed for exposing biological specimens to primary cosmic radiation.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Total load weight 729 pounds

Capsule contents: 61 white mice
42 black mice
Radish seeds
Neurospora genetic samples
Track plates

c. Launch Date: 21 July 1954

Time: 0450 EST

Place: Saulte Sainte Marie, Michigan

Type: Launch arms

d. Flight Data: The balloon failed at 50,000 feet because of the stresses resulting from the high rate of ascent which was caused by accidental ballast release and a jet stream encountered at that altitude. The load, still attached to the balloon, free-fell and landed on Drummond Island, Michigan. It was recovered at 1600 EST, 21 July 1954. All the animals had perished.

AMFL FLIGHT 49

This flight was designed for primary cosmic radiation exposure to biological specimens.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Total load weight 740 pounds

Capsule contents: 50 white mice
36 black mice
1 rabbit
Radish seeds
Neurospora genetic samples
Track plates

c. Launch Date: 25 July 1954

Time: 0530 EST

Place: Saulte Sainte Marie, Michigan

Type: Launch arms

d. Flight Data: The balloon attained a maximum altitude of 95,000 feet and remained above 92,000 feet for 32 hours. Trajectory of the flight remained above 54.7 degrees north geomagnetic latitude. Depressurization of the capsule occurred but command separation could not be accomplished because of vibrator failure of the beacon power supply. Automatic release of load occurred at 1523 EST, 26 July 1954, with impact two miles west of Miles City, Montana. Recovery was effected immediately. All animals succumbed to depressurization of the capsule.

AMFL FLIGHT 50

This flight was primarily designed for primary cosmic radiation exposure to biological specimens.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Total load weight 789 pounds

Capsule contents: 2 monkeys
67 white mice
27 black mice
Radish seeds
Neurospora genetic samples
Track plates

c. Launch Date: 29 July 1954

Time: 0515 EST

Place: Saulte Sainte Marie, Michigan

Type: Launch arms

d. Flight Data: A maximum altitude of 97,000 feet was attained with the balloon remaining above 92,000 feet and 56 degrees north geomagnetic latitude for 33.5 hours. The load was released automatically at 1628 EST, 30 July 1954. Recovery was effected by the radio truck and all animals were recovered satisfactorily. See figures 17 and 18.

AMFL FLIGHT 51

This flight was designed for primary cosmic radiation exposure of biological specimens.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

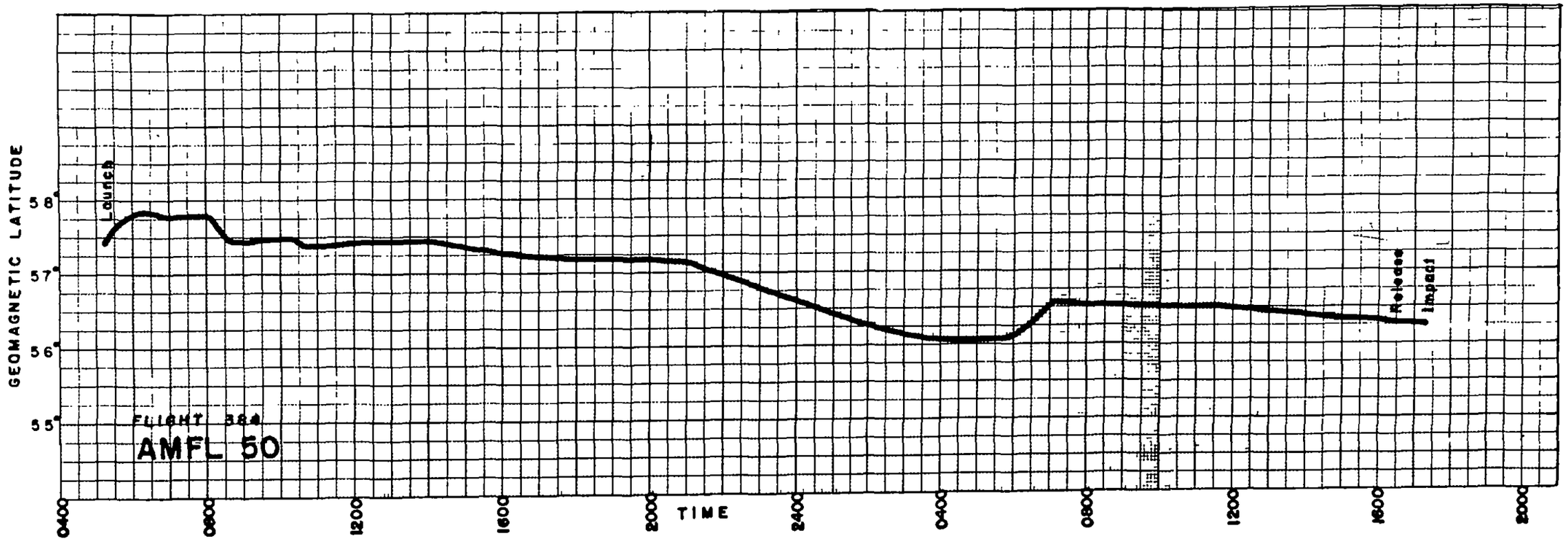


FIGURE 17. Geomagnetic Latitude Curve for Flight 50

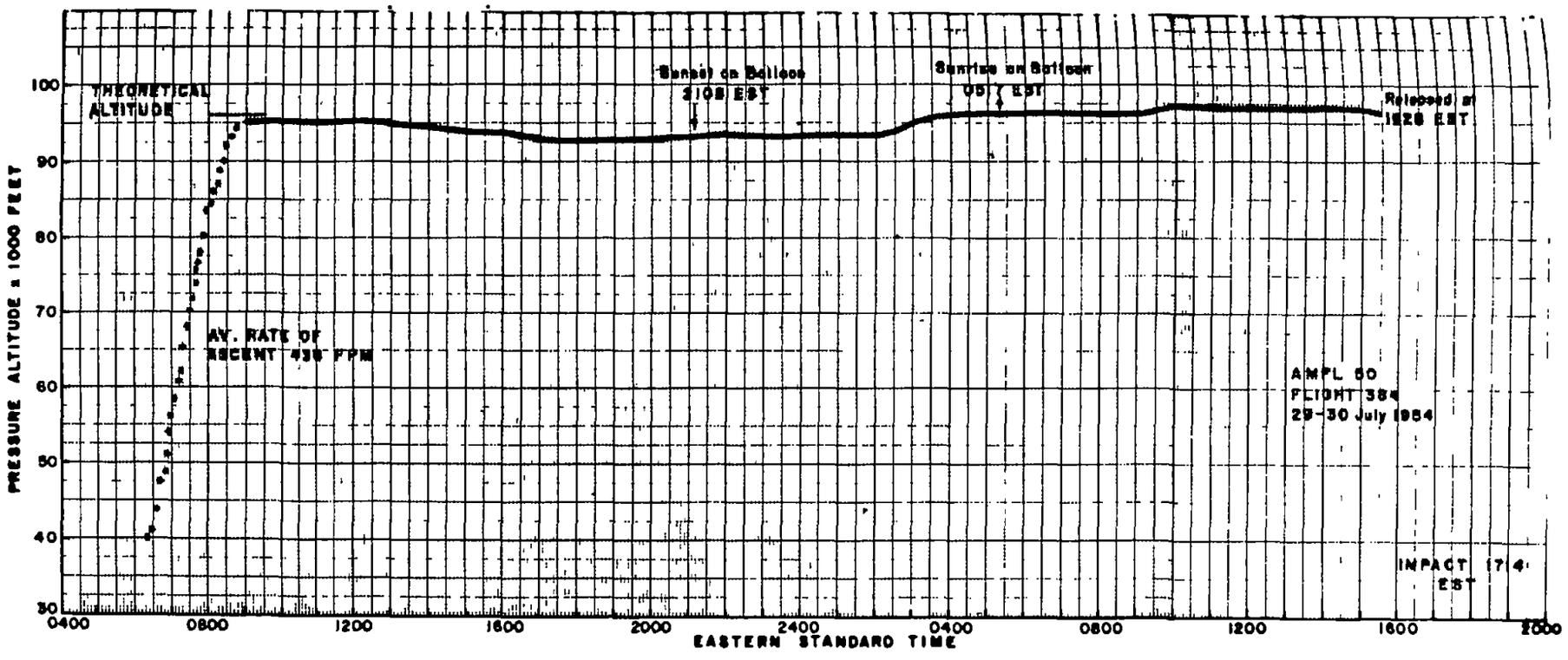


FIGURE 18. Time-Altitude, Temperature, and Pressure Data for Flight 50.

b. Payload: Total load weight 809 pounds

Capsule contents: 2 monkeys
89 white mice
32 black mice
Radish seeds
Neurospora samples
Track plates

c. Launch Date: 2 August 1954

Time: 0508 EST

Place: Saulte Sainte Marie, Michigan

Type: Launch arms

d. Flight Data: A maximum altitude of 96,100 feet was attained. The balloon remained above 90,000 feet and 57.2 degrees north geomagnetic latitude. Load cut-down occurred at 1530 EST, 3 August 1954. Impact was four miles east of Greenbush, Minnesota, and recovery was effected immediately by personnel of the C-47 tracking aircraft. All specimens were recovered in satisfactory condition. See figure 19.

AMFL FLIGHT 52

This flight was designed for exposure of biological specimens to primary cosmic radiation.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Total load weight 847.5 pounds

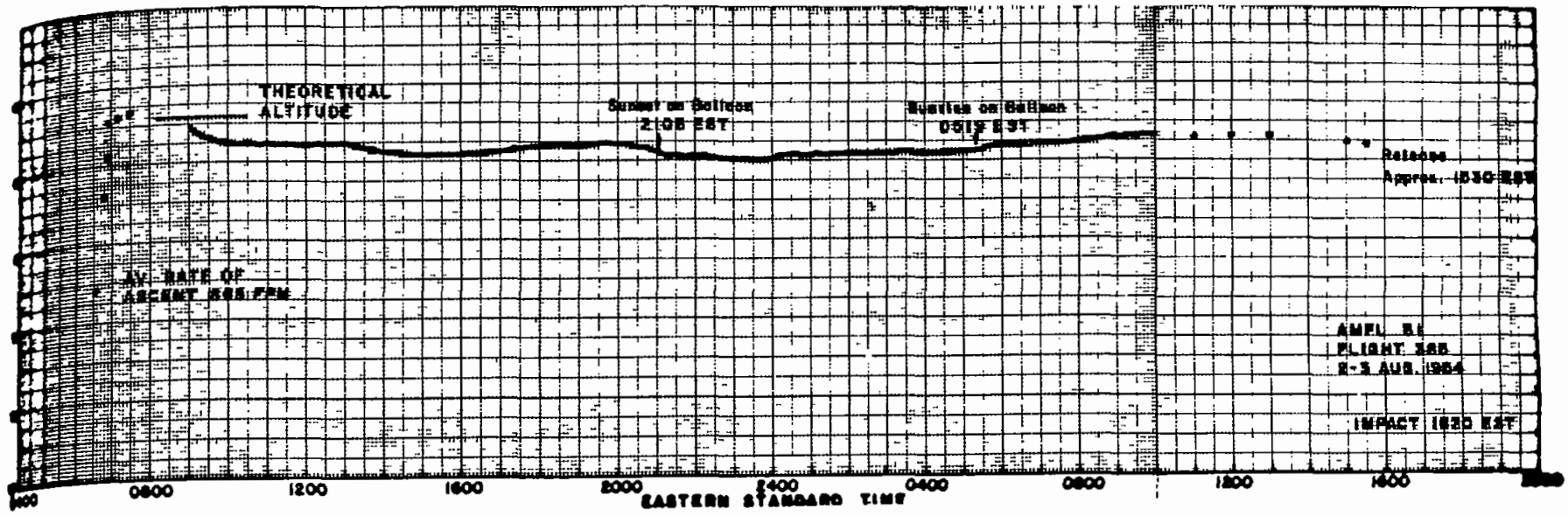
Capsule contents: 63 white mice
39 black mice
15 rats
Neurospora samples
Radish seeds
Track plates

c. Launch Date: 6 August 1954

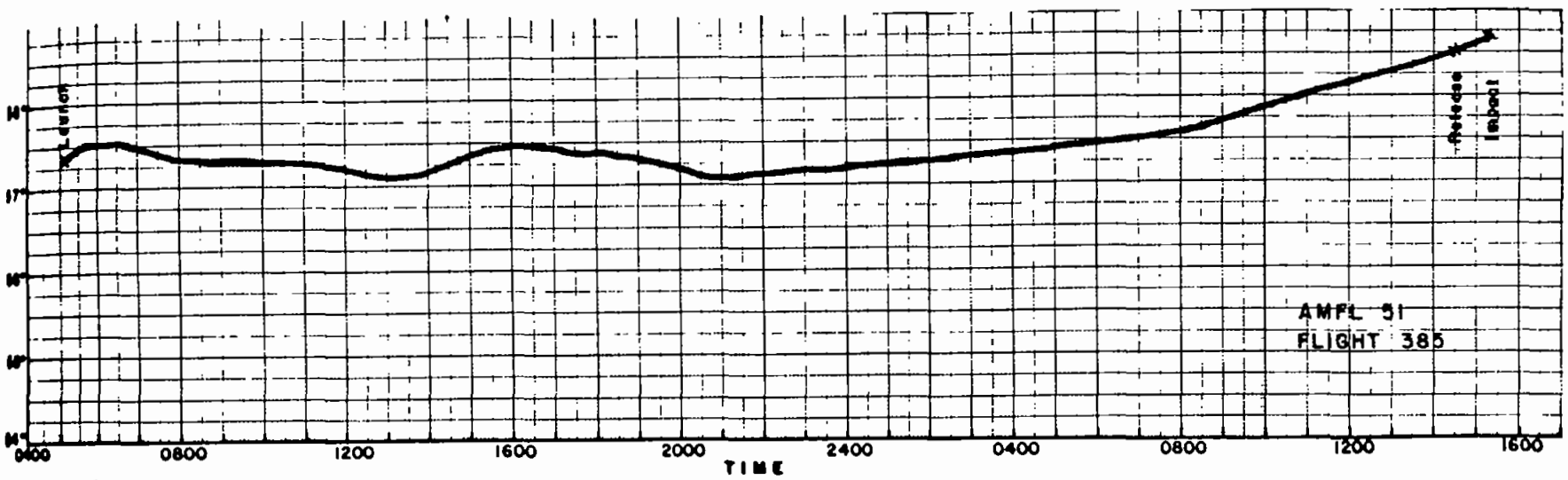
Time: 0630 EST

Place: Saulte Sainte Marie, Michigan

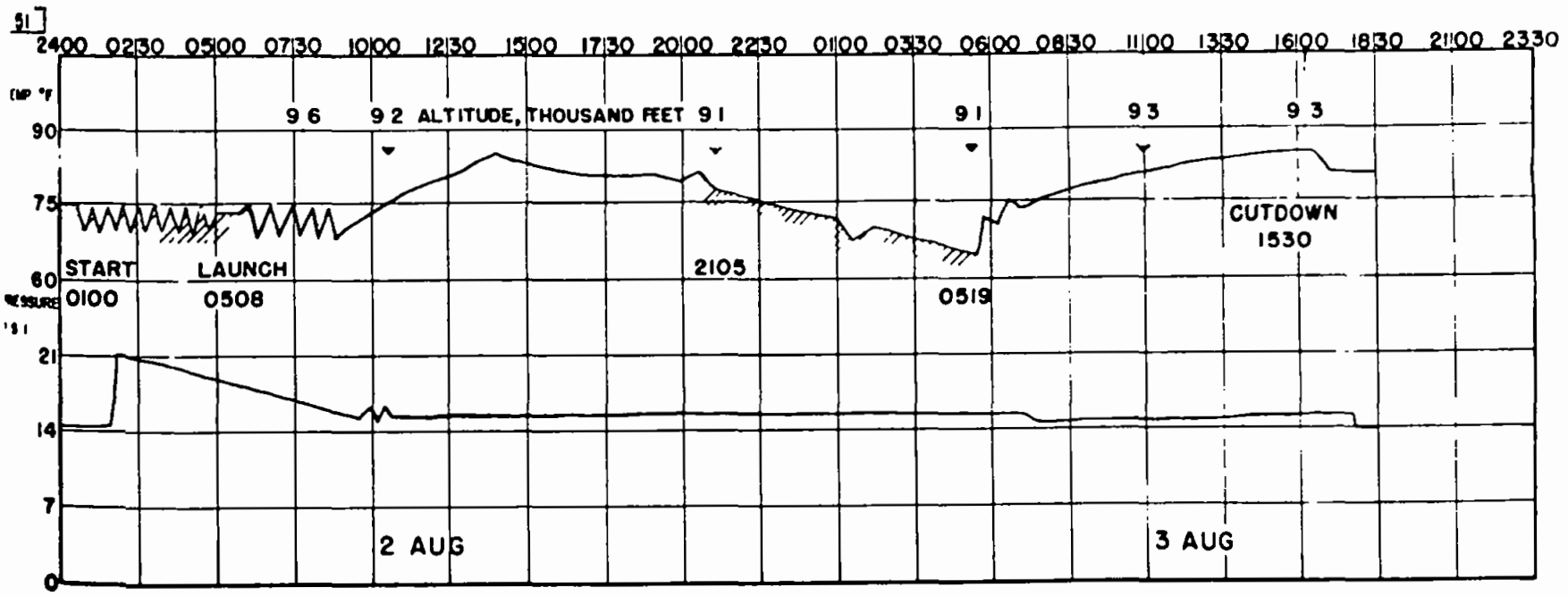
Type: Launch arms



(a) Altitude



(b) Latitude



(c) Temperature-Fressure

FIGURE 19. Data for Flight 51.

d. Flight Data: The balloon attained a maximum altitude of 95,400 feet. Altitude performance was poor, requiring excessive consumption of ballast during the day. An exposure of approximately 17 hours duration was obtained above 90,000 feet and 56.4 degrees north geomagnetic latitude. The balloon descended rapidly during the night and reached the 30,000-foot safety cut-down altitude and was released at 0500 EST, 7 August 1954. Impact occurred at 0522 EST, 15 miles west of Merrill, Wisconsin. Recovery was accomplished at 1120 EST. All animals survived.

AMFL FLIGHT 53

This flight was also designed for primary cosmic radiation exposure to biological specimens.

a. Balloon Type: 116-foot, 2.0 mil Winzen

b. Payload: Total load weight 917.5 pounds

Capsule contents:
75 white mice
15 black mice
15 rats
1 guinea pig
Radish seeds
Neurospora genetic samples
Track plates

c. Launch Date: 10 August 1954

Time: 0541 EST

Place: Saulte Sainte Marie, Michigan

Type: Launch arms

d. Flight Data: The maximum altitude attained was 89,800 feet, and approximately 25 hours exposure above 80,000 feet and 57 degrees north geomagnetic latitude was obtained. The load was cut down by command separation at 1400 EST, 11 August 1954, to prevent descent from being obscured from vision by incoming cloud-cover. However, the load was lost in the clouds and was not discovered until 10 days later. All biological specimens perished.

AMFL FLIGHT 54

This flight was designed for AMFL capsule temperature calibration, both external and internal, using live animals, and also to provide control specimens for previous northern flights.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Capsule and contents, 160 pounds

Capsule contents: 92 white mice
Radish seeds
Track plates

c. Launch Date: 12 October 1954

Time: 0912 MST

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: The maximum altitude attained was 93,200 feet and the balloon remained above 83,000 feet for approximately 24 hours. The payload was released by command separation at 1145 MST, 13 October 1954. Impact was 30 miles west of Roswell, New Mexico, at 1210, with recovery of the payload at 1245. Some of the mice died on this flight; apparently as a result of overcrowding.

AMFL FLIGHT 55

This flight had a three-fold purpose: (1) to serve as a control flight for AMFL specimens, (2) to gather temperature information on ascent and daytime temperatures at altitudes of approximately 90,000 feet, and (3) to photograph performance of 15-foot Frieder parachute upon load release.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Capsule and contents 134 pounds

Capsule contents: 102 white mice
13 black mice
3 guinea pigs
3 petri dishes (TTC prep)
One set of track plates

c. Launch Date: 2 February 1955

Time: 0745

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: Approximately three minutes after launch, the squib fired on the ballast assembly, thus dumping all the ballast. The balloon rose rapidly and at 0751 the parachute and capsule dropped free of the balloon. The package was immediately recovered about three miles northeast of the launch site. No appreciable damage to the capsule occurred and all the animals were recovered alive.

AMFL FLIGHT 56

This flight was designed for the same purpose as AMFL Flight 55 because of the failure of the previous flight.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen

b. Payload: Same as AMFL Flight 55

c. Launch Date: 3 February 1955

Time: 0718 MST

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: The launch was uneventful but at 0821, at approximately 40,000 feet, the balloon encountered severe jet stream and the cut-down mechanism was actuated. No tracking aircraft were in the air at this time and clouds obscured visual tracking from the ground. Radio signals from the balloon failed after the mishap and pattern searches from the air were unproductive.

AMFL FLIGHT 57

The purpose of this flight was to photograph parachute deployment at approximately 115,000 feet altitude. Also, to obtain ground reference photographs, and to test a 145-foot diameter balloon.

a. Balloon Type: 145-foot, 1.5 mil Winzen

b. Payload: 28 pounds

Cameras
Disc type altitude coder
Barograph
Transmitter
Mechanical cutter box
Tissue cultures

c. Launch Date: 12 May 1955

Time: 0547 MST

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: Because of very little free lift, the package bounced on takeoff. The balloon burst at a very high altitude and lack of parachute deployment resulted in a free fall for the packages. Severe damage resulted to most of the equipment. However, the transmitter and altitude coder survived with only minor damage. The tissue cultures appeared unharmed except for a slight displacement from glass surface.

AMFL FLIGHT 59

This flight was primarily designed as a control flight for biological specimens.

a. Balloon type: 150-foot, 1.25 mil Winzen

b. Payload: 72 pounds total

Capsule contents: 51 Black mice
32 white mice
2 guinea pigs
Tissue cultures
Artemia eggs
Track plates

c. Launch Date: 7 June 1955

Time: 0602 MST

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: After launching, the balloon shipped toward Alamogordo, New Mexico, occasionally dragging the instrumentation package on the ground. It was finally caught one mile west of Alamogordo, and while pulling it near the ground in preparation for additional inflation, a small hole was observed in the balloon near the duct opening. The capsule suffered no damage and all biological specimens were recovered in excellent condition.

AMFL FLIGHT 60

This flight was primarily designed to provide capsule temperature data during the high altitude flight, but it also contained biological specimens as controls for northern flights.

a. Balloon Type: 150-foot, 1.25 mil Winzen

b. Payload: 74.5 pounds

Capsule contents: Nuclear track plates
Temperature recording instrumentation
Mice

c. Launch Date: 17 June 1955

Time: 0542 MST

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: The launch was uneventful. The balloon reached floating altitude at 0800 and started a westward trajectory. It began losing altitude at dusk and by 1935 had dropped to 75,000 feet. Command ballast release was attempted, but was unsuccessful. The balloon went over Williams AFB, Arizona, and contact with the balloon was maintained until 2210. At this time radio contact was lost because of automatic release of the capsule. Recovery operations were delayed until the next morning, when the capsule and parachute were spotted from the air and ground crews effected recovery. All animals died because of the delay in recovery.

AMFL FLIGHT 61

This flight was designed to expose biological specimens to primary cosmic particles and to test balloon and instrumentation.

a. Balloon Type: 172.6-foot, 1.2 mil Winzen

b. Payload: 72 pounds

Capsule contents: Track plates
Artemia eggs
Neurospora samples
Tissue cultures
Radio-photoluminescent glass

c. Launch Date: 18 July 1955

Time: 0557

Place: South St. Paul, Minnesota

Type: Launch arms

d. Flight Data: Launch and ascent of the balloon were uneventful. The balloon remained at floating altitude above 110,000 feet for 7 hours and 30 minutes. Tracking was accomplished successfully with recovery of the capsule immediately upon landing 15 miles northwest of Isabelle, South Dakota. The instrumentation functioned satisfactorily except that the altitude coder went off the disc because of an unexpectedly high ceiling. All biological specimens were recovered and returned to the investigator in good condition.

AMFL FLIGHT 62

The primary purpose of this flight was to check performance of ducted balloon and capsule instrumentation. Also, nuclear track plates and tissue cultures were to be exposed to primary cosmic radiation.

a. Balloon Type: Ducted, 172.6-foot, 1.2 mil Winzen

b. Payload: Small capsule and contents 30 pounds

Capsule contents: Nuclear track plates

c. Launch Date: 19 July 1955

Time: 0623

Place: South St. Paul, Minnesota

Type: Launch arms

d. Flight Data: The launch and ascent of the balloon proceeded uneventfully. The balloon reached an altitude of 130,000 feet and spent 6 hours and 50 minutes above 120,000 feet. Tracking proceeded normally, but because of a quick shift in the balloon heading, the aircraft was blinded by the sun and lost visual contact. The balloon landed 30 miles northwest of Miller, South Dakota, and was found by local personnel within 1-1/2 hours. Recovery was effected immediately, but depressurization within the capsule caused moderate damage to the test specimens.

AMFL FLIGHT 63

The primary purpose of this flight was to expose biological specimens to heavy primary cosmic radiation.

a. Balloon Type: 172.6-foot, 1.2 mil Winzen, skirt appendix

b. Payload: Total 208 pounds, capsule and contents 64 pounds

Capsule contents: 91 black mice
4 Artemia samples
Neurospora samples
Track plates

c. Launch Date: 1 August 1955

Time: 0532 CST

Place: International Falls, Minnesota

Type: Launch arms

d. Flight Data: A smooth launch and flight. The balloon ascended to a maximum altitude of 119,000 feet by 1130 CST. Altitude maintenance was good during the 25-hour flight. The landing site was four miles northwest of Fortuna, North Dakota, with immediate recovery accomplished. All biological specimens were recovered in satisfactory condition. See figures 20 and 21.

AMFL FLIGHT 64

a. Balloon Type: 172.6-foot, 1.2 mil Winzen, skirt appendix

b. Payload: Total 280 pounds, capsule and contents 74 pounds

Capsule contents: 12 guinea pigs
4 Artemia samples
Cytological specimens
Neurospora samples
Track plates

c. Launch Date: 5 August 1955

Time: 0530 CST

Place: International Falls, Minnesota

Type: Launch arms

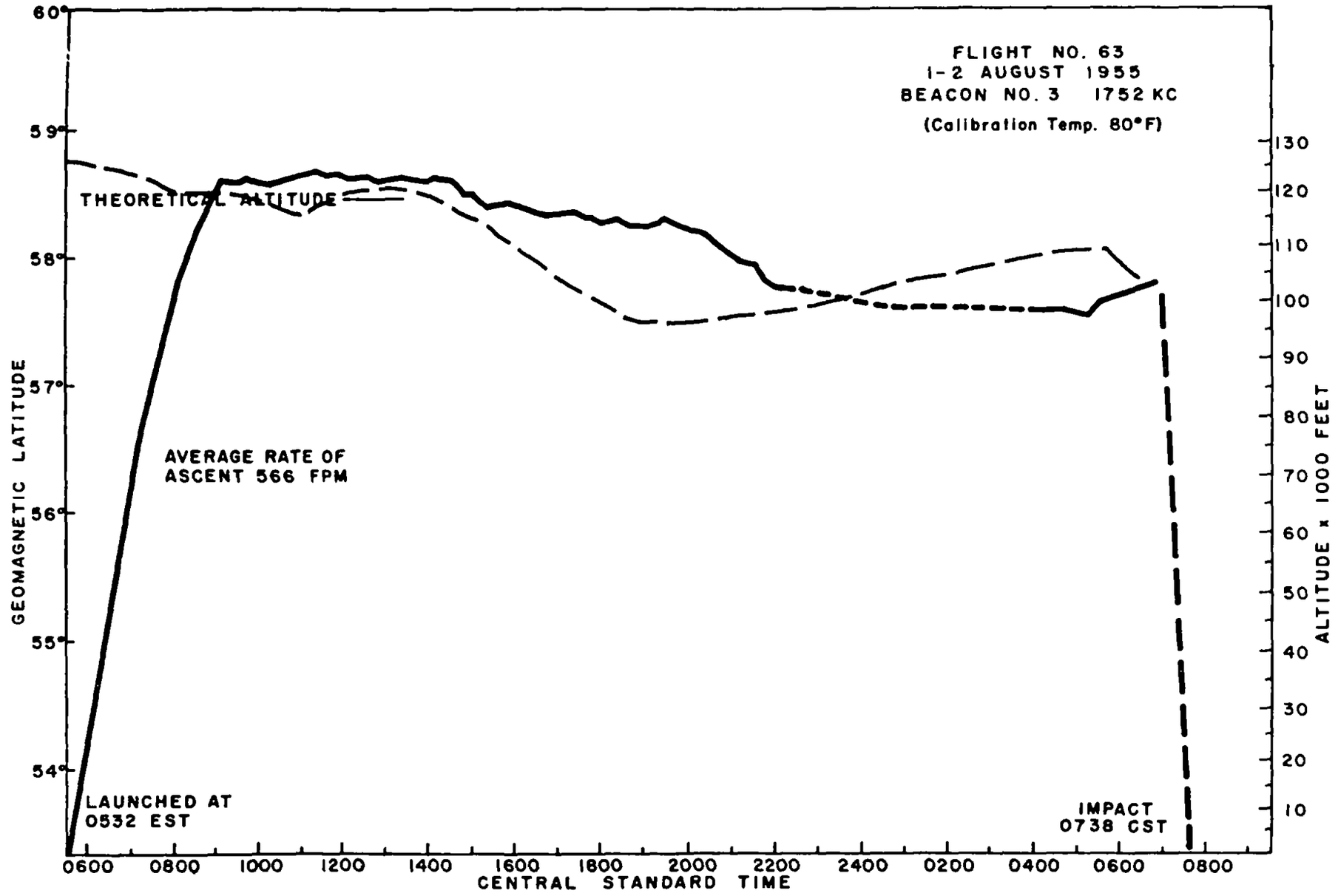
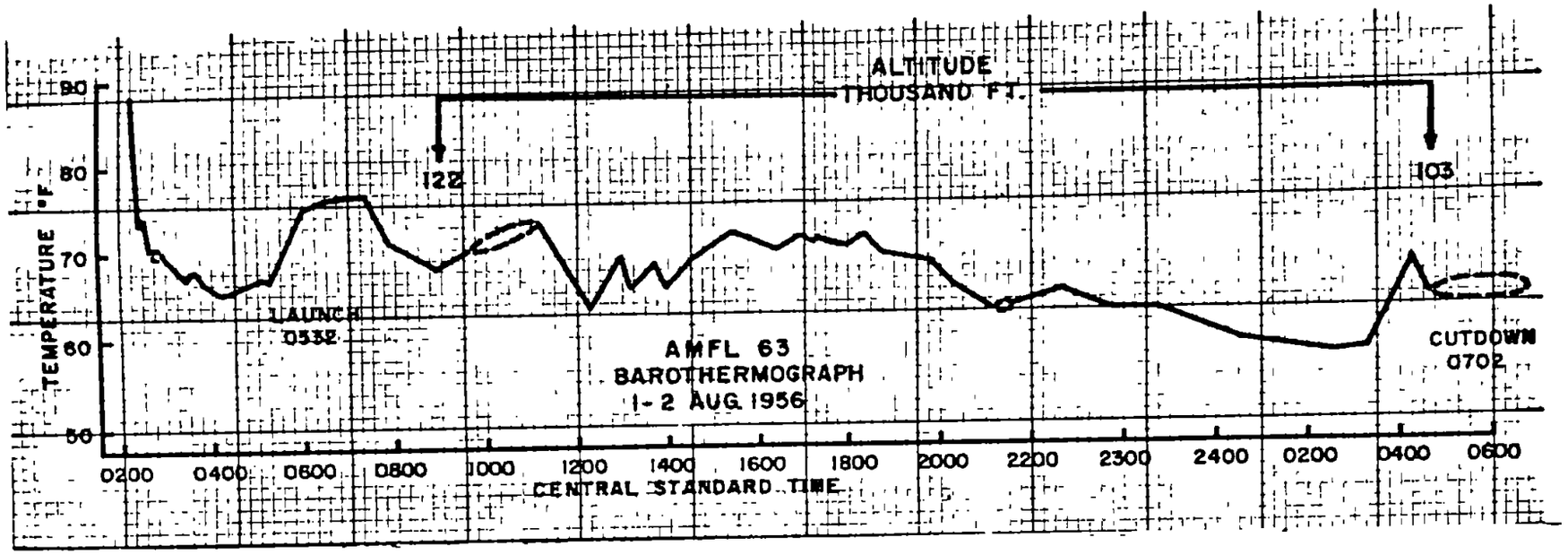


FIGURE 20. Time-Altitude Data for Flight 63



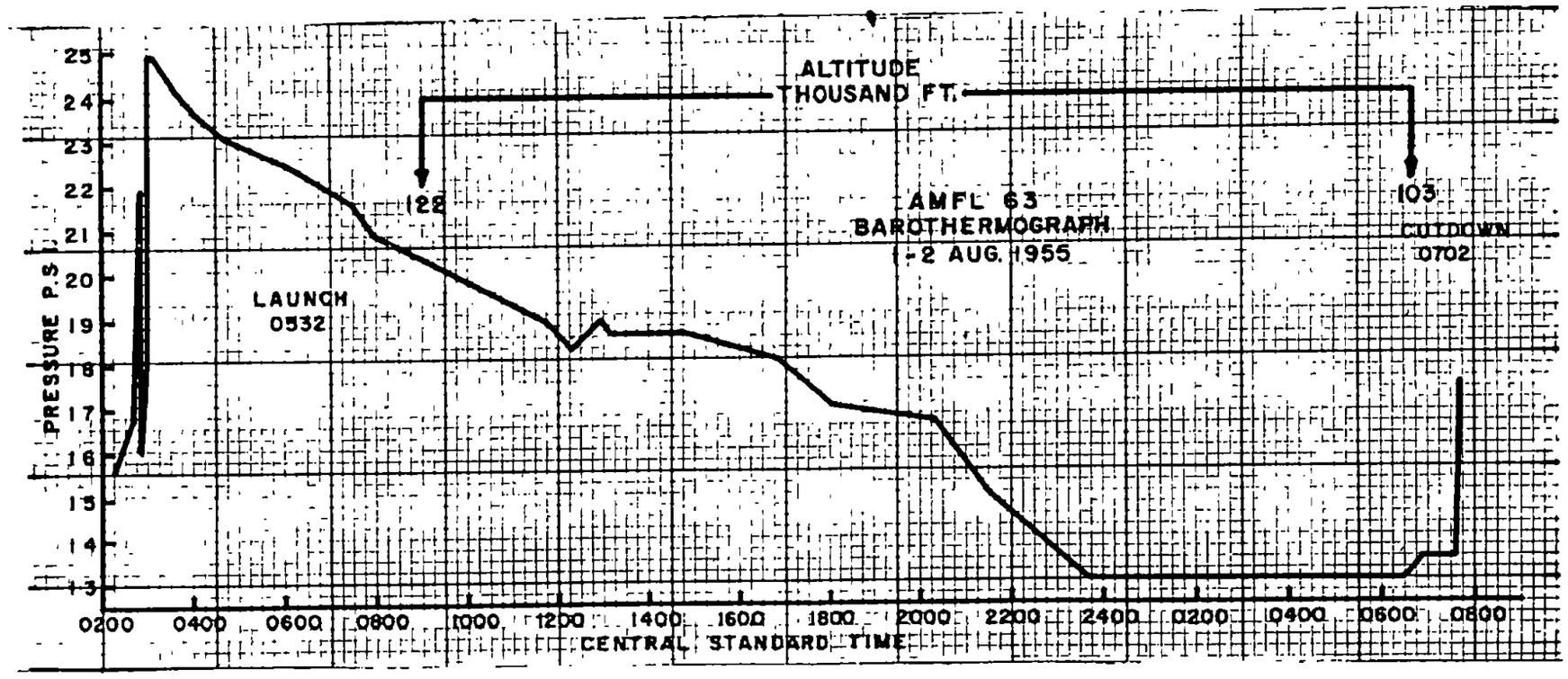


FIGURE 21. Temperature and Pressure Data for Flight 63.

d. Flight Data: The launch and ascent of the balloon were uneventful. The rate of ascent was 719 fpm, with maximum altitude of 115,000 feet attained. An average altitude of 114,000 feet was maintained throughout the 26-hour flight. The landing site was 5 miles north of Mohall, North Dakota, with recovery effected immediately. All animals died because of excessive capsule temperature resulting from malfunction of the cooler motor.

AMFL FLIGHT 65

The purpose of this flight was to obtain primary cosmic ray exposure for biological specimens.

a. Balloon Type: 172.6-foot, 1.2 mil Winzen, skirt appendix

b. Payload: Total 290 pounds, capsule and contents 74 pounds

Capsule contents: 11 guinea pigs
4 Artemia samples
Cytological specimens
Track plates

c. Launch Date: 8 August 1955

Time: 0512 CST

Place: International Falls, Minnesota

Type: Launch arms

d. Flight Data: The balloon launch was excellent and the balloon ascended at a rate of 550 fpm to a maximum altitude of approximately 126,000 feet. Altitude maintenance was good throughout the 27-hour flight. See figures 22 and 23. The landing site was 10 miles northeast of Medicine Lake, Montana. Recovery was effected immediately and the biological specimens were recovered in good condition.

AMFL FLIGHT 66

This flight was designed to obtain primary cosmic ray exposure for biological specimens.

a. Balloon Type: 120.8-foot, 1.5 mil Winzen, skirt appendix

b. Payload: Total 329 pounds, capsule and contents 63 pounds

Capsule contents: 93 black mice
4 Artemia samples
Track plates

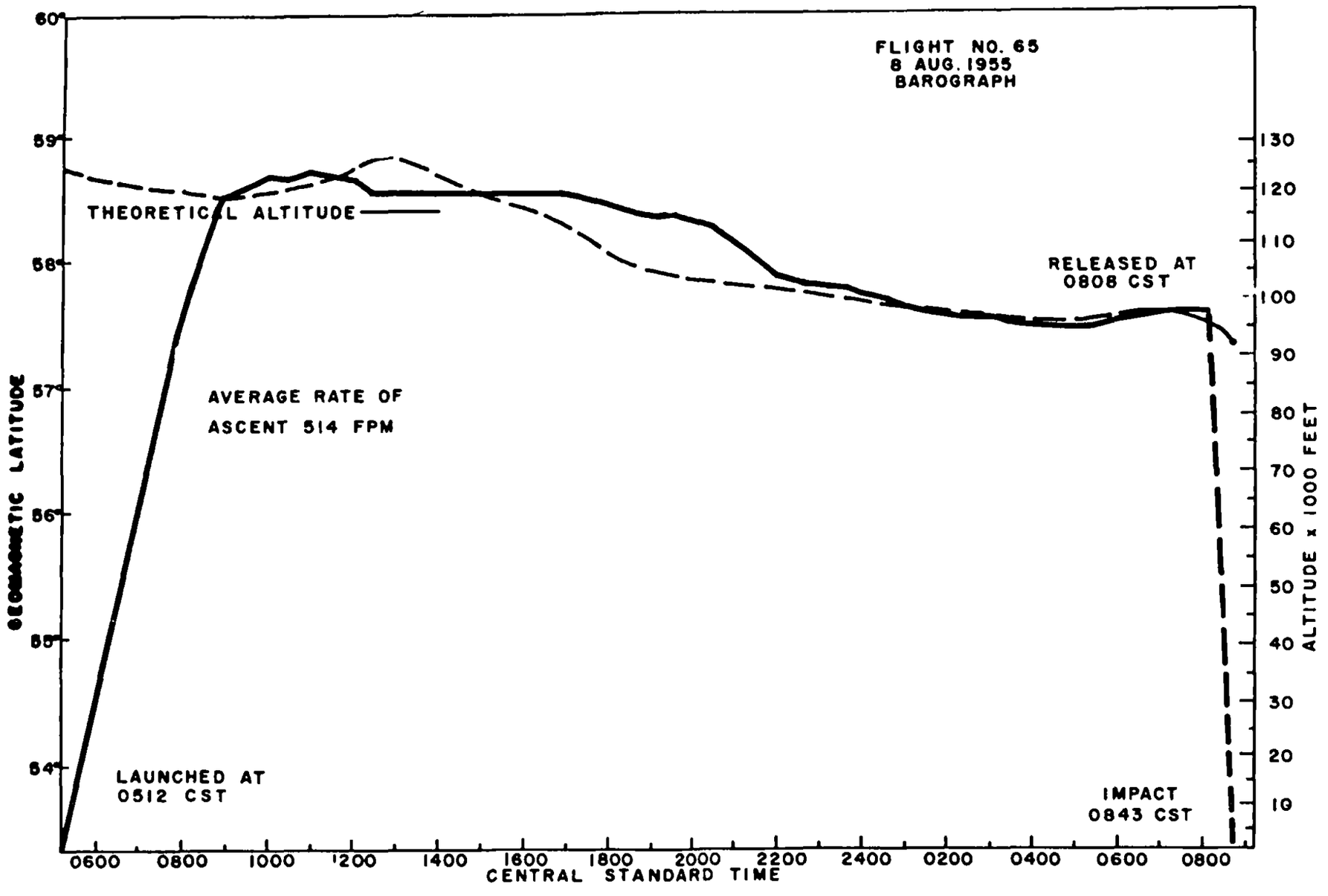
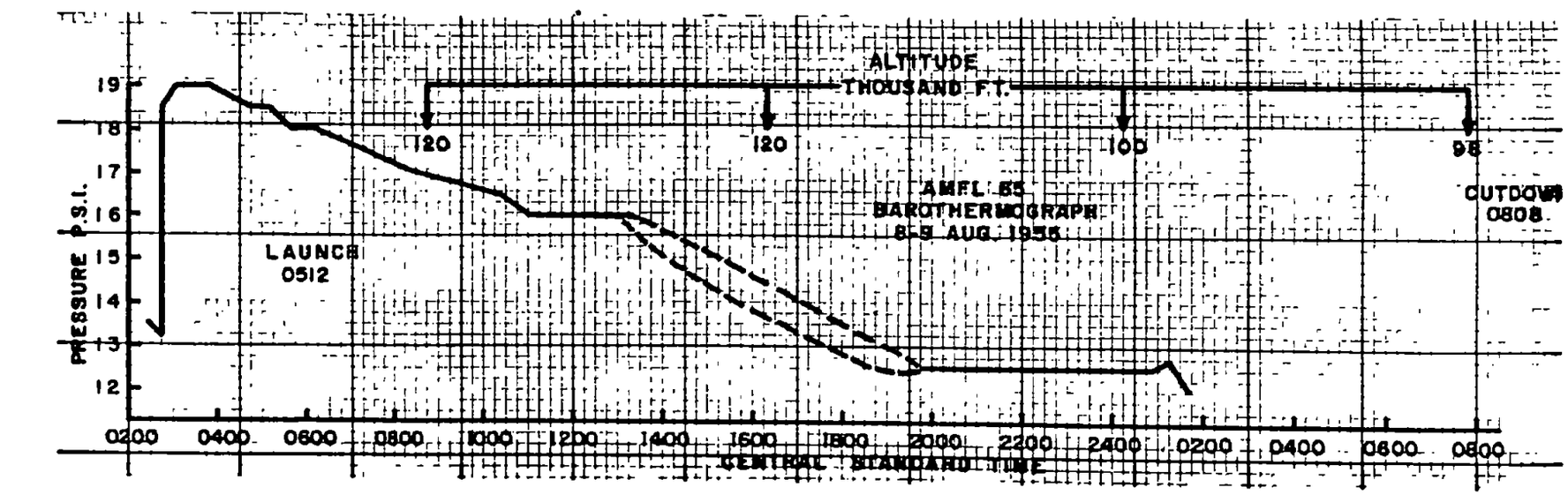


FIGURE 22. Time-Altitude Data for Flight 65.



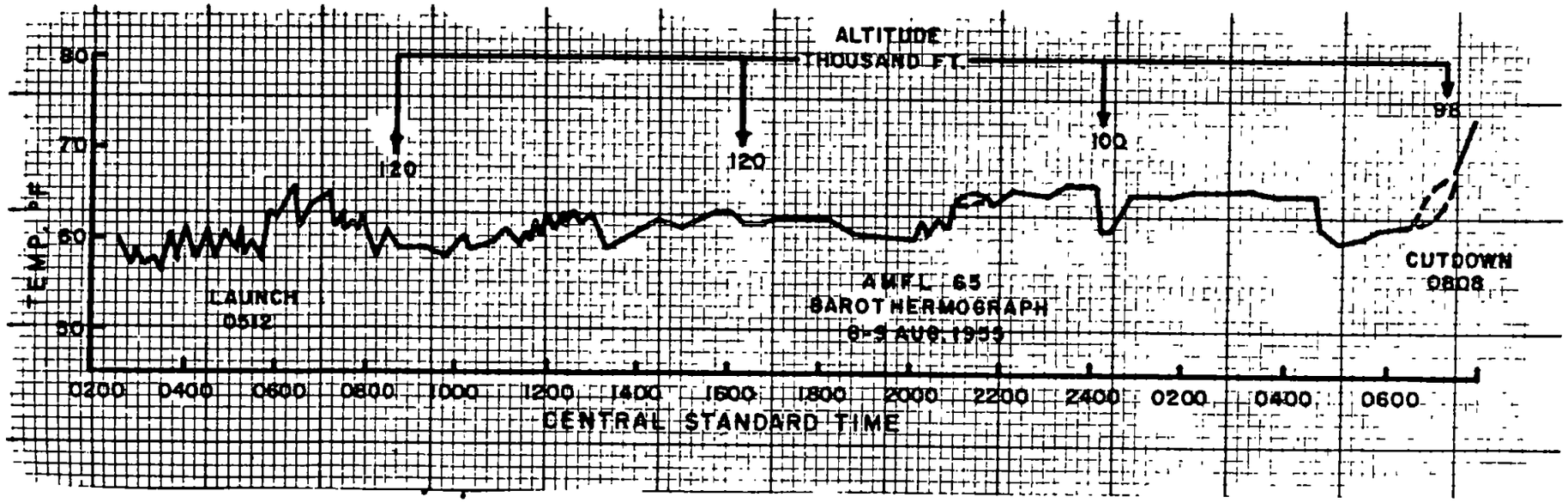


FIGURE 23. Temperature and Pressure Data for Flight 65.

c. Launch Date: 11 August 1955

Time: 0531 CST

Place: International Falls, Minnesota

Type: Launch arms

d. Flight Data: The launch was uneventful. Rate of ascent was only 424 fpm which resulted in a trajectory for the balloon, causing it to land in Canada. Maximum altitude attained was 92,000 feet, with excellent altitude maintenance during the 25-hour flight. The balloon landed four miles north of Pilot Mound, Manitoba, Canada. The recovery of the capsule was effected immediately by plane and truck and all specimens were found in excellent condition.

AMFL FLIGHT 67

This flight was designed for primary cosmic ray exposure of biological specimens. Two capsules were used to obtain full utilization of the larger balloon being employed.

a. Balloon Type: Double duct, "pigtail" appendix

Weight: 526 pounds

Size: 172.6-foot, 1.2 mil Winzen

b. Payload: Two AMFL capsules, 140 pounds total

Capsule No. 1: 93 Bagg Strain mice
4 boxes Artemia eggs
2 containers cytological specimens
1 package Neurospora

Capsule No. 2: 93 white mice
24 tissue cultures in Rose chambers

Instrumentation, 49 pounds

Ballast dropper and recorder, 24 pounds

Ballast, 100 pounds

c. Launch Date: 22 August 1955

Time: 0545 CST

Place: International Falls, Minnesota

Type: Launch arms

d. Flight Data: The balloon ascended at an average rate of 746 fpm and reached a maximum pressure altitude of 6.2 millibars. The duration of exposure at various altitudes was approximately as follows:

1. Above 110,000 feet: 5 hours

2. 105,000 to 110,000 feet: 6 hours, 50 minutes

3. Total exposure above 80,000 feet: 22 hours

e. Tracking and Recovery: Tracking was performed from the radio van at International Falls, Minnesota, an Air Force C-47, the contractor's Twin Beechcraft, and a radio truck. Separation of the balloon and payload occurred at 0706 CST, 23 August 1955, and the load landed two miles southeast of Middle River, Minnesota. The load was reached promptly by the radio truck and a vehicle supplied by the contractor for transportation of personnel required to process the biological specimens. One capsule depressurized, resulting in the death of all the animals in that capsule. All the animals in the other capsule were recovered in good condition.

AMFL FLIGHT 68

This flight was designed to obtain extended exposure of C-57 mice for leukemia studies, mice and guinea pigs for neurocytological studies and tissue cultures.

a. Balloon Type: Bicornuate ducted appendix

Weight: 542 pounds

Size: 172.6-foot, 1.2 mil Winzen

b. Payload: AMFL capsule, 69 pounds

Capsule contents: 107 C-57 mice
3 guinea pigs
12 tissue cultures in Rose chambers
3 boxes of Artemia eggs
2 containers cytological specimens

Instrumentation: 50 pounds

Ballast dropper: 15 pounds

Ballast: 185 pounds

c. Launch Date: 31 August 1955

Time: 0552 CST

Place: International Falls, Minnesota

Type: Launch arms

d. Flight Data: The balloon ascended at an average rate of 988 fpm and attained a maximum pressure altitude of 4.5 millibars. The duration of exposure at altitude was approximately as follows:

1. Above 120,000 feet: 4 hours, 45 minutes

2. 115,000 to 120,000 feet: 14 hours, 30 minutes

3. 110,000 to 115,000 feet: 3 hours, 20 minutes

4. Total exposure above 96,000 feet: 23 hours, 10 minutes

e. Tracking and Recovery: Tracking was performed by the same elements as were employed for Flight 67. Separation of the balloon and payload occurred at 0705 CST, 1 September 1955. The packages landed four miles northeast of Pine Island, Minnesota, in impenetrable swamp country. The packages were removed at 1330 CST the same day by an Air Force helicopter which had been flown from Minneapolis. The packages were taken to Pine Island by the helicopter where the personnel required for autopsy and preparation of the specimens had been assembled. All animals died as a result of the delay in the recovery of the capsule.

AMFL FLIGHT 69

This flight was designed to obtain maximum altitude exposure of specimens, and to check the altitude performance of this balloon by means of the University of Iowa recording high altitude altimeter.

a. Balloon Type: Single ducted appendix

Weight: 563 pounds

Size: 172.6-foot, 1.2 mil Winzen

b. Payload: AMFL capsule, 33 pounds

Capsule contents: 1 guinea pig
10 C-57 mice
8 tissue cultures

Instrumentation: 10 pounds

Ballast: None

Recording altimeter: 15 pounds

c. Launch Date: 1 September 1955

Time: 0550 CST

Place: International Falls, Minnesota

Type: Launch arms

d. Flight Data: The balloon ascended at a normal rate and floated between 115,000 and 120,000 feet during the first day. The balloon cut-down mechanism failed to operate as scheduled at 1600 CST, 1 September 1955, and the balloon continued to float for several days. The impact site is unknown, presumably in the northwestern Atlantic Ocean or northeast Canada.

e. Tracking and Recovery: Tracking was performed by the same elements used for tracking Flight 67. No attempt to track the balloon was made after the first night inasmuch as the specimens could not have survived any longer. The equipment and data from this flight have not been recovered.

AMFL FLIGHT 70

Because of launching complications, flight operations were transferred to South St. Paul, Minnesota. Flight 70 was designed for the same purpose as Flight 69 which was lost.

a. Balloon Type: Standard skirt appendix

Weight: 507 pounds

Size: 172.6-foot, 1.2 mil Winzen

b. Payload: AMFL capsule, 67 pounds

Capsule contents: 32 C-57 mice
3 guinea pigs
23 tissue cultures
1 package of track plates

Instrumentation: 5 pounds

Ballast: None

c. Launch Date: 12 September 1955

Time: 0645 CST

Place: South St. Paul, Minnesota

Type: Launch arms

d. Flight Data: The balloon ascended at a rate of 861 fpm and attained a floating altitude between 120,000 and 130,000 feet.

e. Tracking and Recovery: Tracking was primarily performed visually from the ground by personnel at the Winzen Flight Center, by the radio truck, and by the Twin Beechcraft. The payload cut down at 1600 CST, 12 September 1955, and landed 10 miles northwest of Willmar, Minnesota. It was reached promptly by the radio truck and a contractor-supplied vehicle with the personnel required for sacrifice and preparation of the specimens. All animals were recovered in excellent condition.

AMFL FLIGHT 71

This flight was designed to obtain a 30-hour exposure of a maximum number of specimens to make up for the loss of one capsule on Flight 67 and the capsule on Flight 69.

a. Balloon Type: Open skirt appendix

Weight: 507 pounds

Size: 172.6-foot, 1.2 mil Winzen

b. Payload: AMFL capsule, 64 pounds

Capsule contents: 73 C-57 mice
40 Bagg Strain mice
1 package track plates

Instrumentation: 10 pounds

Ballast: None

c. Launch Date: 20 September 1955

Time: 0615 CST

Place: South St. Paul, Minnesota

Type: Launch arms

d. Flight Data: The balloon ascended at an average rate of 1014 fpm and reached a maximum pressure altitude of approximately 2.5 millibars. It remained above 115,000 feet the first day but descended rapidly the first night because of heavy clouds, and floated at approximately 90,000 feet the second day. The cut-down mechanism which was set to operate at 1500 CST, 21 September 1955, failed to function and the balloon continued to float.

e. Tracking and Recovery: Tracking was performed from theodolite stations, the radio truck, and the contractor's Twin Beechcraft. Recovery has not been effected.

AMFL FLIGHT 72A

The purpose of this flight was two-fold. First, it was to serve as a control flight for test materials flown on northern flights in 1955. Second, the flight was to provide additional data on night temperatures above 110,000 feet altitude.

a. Balloon Type: Stressed tape, 172.6-foot, 1.2 mil Winzen

b. Payload: AMFL capsule, 88 pounds

Capsule contents: 52 mice
5 guinea pigs
24 test tubes of Neurospora
8 packages of track plates
6 vials of barley seeds

Instrumentation: 85 pounds

Ballast hopper: 6 pounds

Ballast: 180 pounds

c. Launch Date: 29 November 1955

Time: 2130

Place: Holloman AFB, New Mexico

Type: Roller arms - captive

d. Flight Data: After the balloon was captured by the crane, an 80-degree cross wind caught the balloon and made two-thirds of it flare out horizontally about five feet above the ground like an enormous sail. After approximately thirty seconds, the balloon started to rotate and twist in the wind. The balloon had rotated about 90 degrees

when, because of the strain imposed upon them, the circumferential stress tapes around the apex of the balloon parted, after which the balloon settled to the ground. The results indicate that this type of launch technique is not adequate for the large-sized balloons constructed to minimum safety factors to reach maximum altitudes.

AMFL FLIGHT 72B

The purpose of this flight was the same as for Flight 72A.

a. Balloon Type: Bicornuate duct

Weight: 530 pounds

Size: 172.6-foot, 1.2 mil Winzen

b. Payload: AMFL capsule, 74 pounds

Capsule contents: 70 mice
5 guinea pigs
29 test tubes of Neurospora
8 vials of Drosophila
11 packages of track plates

Instrumentation: 85 pounds

Ballast hopper: 6 pounds

Ballast: 150 pounds

c. Launch Date: 11 February 1956

Time: 0945 MST

Place: Holloman AFB, New Mexico

Type: Launch arms

d. Flight Data: The balloon ascended at an apparently normal rate and floated between 100,000 and 115,000 feet the first day. Attempts to cut down the gondola after 24 hours failed. Attempts from Holloman AFB, as well as from the van at Mineral Wells, Texas, were unsuccessful. Therefore, the balloon continued to float until the automatic cut-down effected termination at 1545 CST, 12 February 1956.

e. Tracking and Recovery: A weapons carrier and panel truck were sent to Jackson, Mississippi, and a radio van and a panel truck were dispatched to Mineral Wells, Texas. An Air Force C-47 was used for aerial tracking. After separation of the balloon and payload, the

gondola parachuted to earth about five miles northeast of Arkadelphia, Arkansas. State troopers were contacted from the aircraft, but they were unable to locate the gondola. Therefore, the C-47 landed at Hot Springs, Arkansas, and the recovery crew proceeded to Arkadelphia via a State trooper's vehicle. The gondola was located at 1930 CST. All of the animals were recovered in good condition. See figure 24.

AMFL FLIGHT 73

The purpose of this flight was two-fold: (1) it was designed to serve as a control flight for previous northern flights, and (2) a fiberglas type of capsule was to be flown for the first time to permit an evaluation of its performance in flight.

a. Balloon Type: Stressed tape, 72.8-foot, 1.5 mil Winzen

b. Payload: AMFL capsule, 43 pounds

Capsule contents: 1 package track plates
23 test tubes Neurospora

Instrumentation: 66.5 pounds

c. Launch Date: 10 April 1956

Time: 0658 MST

Place: Holloman AFB, New Mexico

Type: Covered wagon

d. Flight Data: The balloon ascended at an apparently normal rate and attained a peak altitude of 85,700 feet. This peak was achieved at 0830, but at 0850 the balloon was down to 83,000 feet. By 0910 the balloon was at 75,000 feet and thereafter the descent was at a more rapid rate. When the balloon reached 50,000 feet at 1047, command cut-down was effected.

e. Tracking and Recovery: An Air Force L-20 was used for aerial tracking. A radio panel truck and weapons carrier were used for ground tracking and recovery. The area of impact was 15 miles south of Hope, New Mexico. The capsule and contents were immediately recovered with all specimens in good condition.

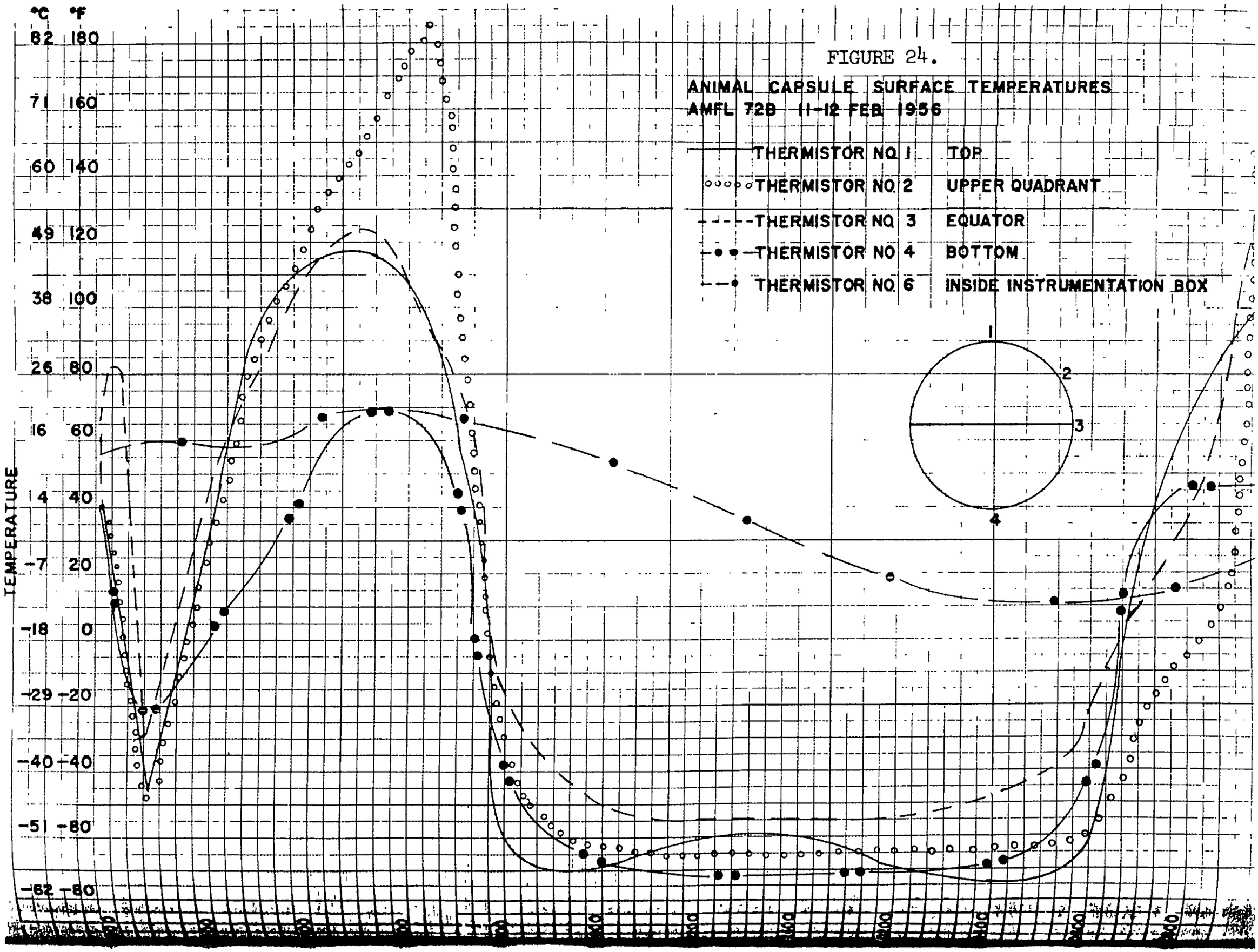
MANHIGH CAPSULE TEMPERATURE TEST FLIGHT

This flight was primarily designed to study daytime temperature balance on the MANHIGH capsule and to obtain data on the gondola parachute recovery system when released at high altitude. In addition, biological specimens were included in the capsule to obtain primary cosmic ray exposure.

FIGURE 24.

ANIMAL CAPSULE SURFACE TEMPERATURES
AMFL 728 11-12 FEB 1956

———	THERMISTOR NO 1	TOP
○○○○	THERMISTOR NO 2	UPPER QUADRANT
- - - -	THERMISTOR NO 3	EQUATOR
—●●—	THERMISTOR NO 4	BOTTOM
—●—	THERMISTOR NO 6	INSIDE INSTRUMENTATION BOX



a. Balloon Type: Bicornuate duct

Size: 200.2-foot, 1.5 mil Winzen

Volume: 3,000,000 cubic feet

Weight: 1046 pounds

b. Payload: MANHIGH capsule and contents, 863 pounds

Biological specimens: 10 guinea pigs
mice

c. Launch Date: 14 April 1957

Time: 0718 CST

Place: South St. Paul, Minnesota

Type: Roller platform

d. Flight Data: Balloon launch was accomplished very smoothly. The rate of ascent was 500 fpm and an altitude of 103,500 feet was attained by 1035 CST. Balloon radio contact was maintained throughout the flight and balloon tracking was uneventful. The capsule was cut loose by the automatic timer at 1745 CST. The capsule descended very smoothly and landed in a suburban area of Saginaw, Michigan. Recovery was effected immediately.

All animals were recovered in generally good condition. The mice were lost because of heater failure in the garage where they were housed the night following the flight.

JIG I FLIGHT

This flight was one of a series of six, designed to provide primary cosmic ray exposure to various biological test systems. It was planned for this flight to reach an altitude of 2.5 millibars for a duration of 10 hours. Three attempts to launch this flight were unsuccessful and subsequently the entire series was cancelled.

a. Balloon Type: Tailored tapeless

Size: 235-foot, 0.75 mil Winzen

Volume: 5,000,000 cubic feet

Weight: 650 pounds

b. Payload: AMFL capsule and contents, 81 pounds

Capsule contents: 1 monkey
Goldfish
Drosophila larvae
Neurospora spores

c. Launch No. 1 Date: 19 July 1958

Time: 0657

Place: International Falls, Minnesota

Type: Roller launch arms

Launch No. 2 Date: 30 July 1958

Time: 0703

Place: Crosby, Minnesota

Type: Open pit mine

Launch No. 3 Date: 7 August 1958

Time: 0555

Place: Crosby, Minnesota

Type: Open pit mine

d. Flight Data: The first launch attempt was made with launch arms. After inflation, and upon release of the launch arms, the rapid transverse movement of the helium placed excessive tension on the balloon and caused it to rupture immediately.

The second attempt was made from an open pit mine. The balloon ascended normally to an altitude of approximately 50,000 feet. At this altitude, it encountered a jet stream and the balloon ruptured. The ruptured balloon and capsule free-fell to earth and immediate recovery was accomplished. Miraculously, the biological specimens sustained no damage and the capsule was only slightly dented.

The third attempt was again made from an open pit mine. The launch and initial ascent were uneventful. The balloon ascended to approximately 63,000 feet and burst. This is well above where it would have encountered severe winds. The ruptured balloon and capsule free-fell to earth and recovery was effected within 45 minutes. The capsule was quite severely dented, but the biological specimens sustained no apparent damage.

TABLE III

AEROMEDICAL FIELD LABORATORY BALLOON FLIGHTS

AMFL NR	DATE LAUNCHED	LAUNCH SITE
40	11 Feb 54	Holloman AFB, New Mexico
41	23 Feb 54	Holloman AFB, New Mexico
42	5 Mar 54	Holloman AFB, New Mexico
43	12 Mar 54	Holloman AFB, New Mexico
44	24 Jun 54	Holloman AFB, New Mexico
45	7 Jul 54	Fleming Field, Minnesota
46	15 Jul 54	Saulte Sainte Marie, Michigan
47	18 Jul 54	Saulte Sainte Marie, Michigan
48	21 Jul 54	Saulte Sainte Marie, Michigan
49	25 Jul 54	Saulte Sainte Marie, Michigan
50	29 Jul 54	Saulte Sainte Marie, Michigan
51	2 Aug 54	Saulte Sainte Marie, Michigan
52	6 Aug 54	Saulte Sainte Marie, Michigan
53	10 Aug 54	Saulte Sainte Marie, Michigan
54	12 Oct 54	Holloman AFB, New Mexico
55	2 Feb 55	Holloman AFB, New Mexico
56	3 Feb 55	Holloman AFB, New Mexico
57	12 May 55	Holloman AFB, New Mexico
59	7 Jun 55	Holloman AFB, New Mexico
60	17 Jun 55	Holloman AFB, New Mexico

TABLE III, CONTINUED

AMFL NR		DATE LAUNCHED	LAUNCH SITE
61		18 Jul 55	South St. Paul, Minnesota
62		19 Jul 55	South St. Paul, Minnesota
63		1 Aug 55	International Falls, Minnesota
64		5 Aug 55	International Falls, Minnesota
65		8 Aug 55	International Falls, Minnesota
66		11 Aug 55	International Falls, Minnesota
67		22 Aug 55	International Falls, Minnesota
68		31 Aug 55	International Falls, Minnesota
69		1 Sep 55	International Falls, Minnesota
70		12 Sep 55	South St. Paul, Minnesota
71		20 Sep 55	South St. Paul, Minnesota
72A		29 Nov 55	Holloman AFB, New Mexico
72B		11 Feb 56	Holloman AFB, New Mexico
73		10 Apr 56	Holloman AFB, New Mexico
MANHIGH Temp Test		14 Apr 57	South St. Paul, Minnesota
JIG I	a.	19 Jul 58	International Falls, Minnesota
	b.	30 Jul 58	Crosby, Minnesota
	c.	7 Aug 58	Crosby, Minnesota

VI. RESULTS

A. Balloon Performance and Capsule Design

From experience gained during the flights discussed in this report, it was possible to obtain balloon flights at very high altitudes floating at a rather stable level. This was achieved by using larger balloons, decreasing the weight of capsule and instrumentation, modifying ballast control, and increasing the reliability of the instruments. Weight was reduced by substituting a fiberglas capsule for the aluminum type used previously, plus a miniaturization of capsule components. Temperature control was perfected, as well as carbon dioxide and oxygen control. Balloon altitude data were transmitted to earth by means of a coded cylinder type pressure indicator, modeled after a pressure indicator devised by General Mills, Inc. Tracking and recovery procedures were greatly improved, which allowed better control of the flights at all times, and prompt recovery upon termination of the flight. This is, of course, of major importance when biological test systems are utilized.

B. Biological Test System

1. Effects on Exposed Primates (Ref. 12)

The two monkeys, both of which were exposed on Flights 50 and 51, were observed for six months and no significant effects were detected which could be attributed to their exposure to primary cosmic radiation.

The psychological test history of these animals includes the following post-exposure evaluations:

a. The weight and general behavior of each animal were closely observed during the entire post-flight period.

b. The discontinuous pursuit performance was retested on these animals for ten days immediately following exposure.

c. The animals were retested on planometric discrimination problems for a period of six weeks.

d. The animals were tested on oddity problems during the next four weeks.

e. The animals' appetites for peanuts and raisins were tested, using the Wisconsin Appetite Test during a two-week period.

f. The animals were tested for their ability to solve simple and complex delayed response problems over a period of four weeks.

g. This entire series of tests was repeated in four months as follows: discontinuous response pursuit performance (10 days), planometric discrimination problems (6 days), oddity problems (5 days), delayed response problems (5 days) and the Wisconsin Appetite Test (4 days). On all tests, there were no significant statistical differences between the exposed and control animals. The exposed animals showed no deterioration of performance compared to preflight tests. One animal survived two years and the other is still in good condition four years post-flight.

Thus, the negative results are of value by demonstrating the absence of detectable deterioration of performance from exposures of this duration to primary cosmic radiation.

2. Mouse Longevity Study

The statistically small number of mice comprising this experiment precludes definitive results. In this experiment, however, the longevity curves for the experimental and control groups appear to parallel each other. In a series of experiments by Upton (Ref. 31), several groups of mice were exposed at an early age to 30 rad of X-rays and other groups to 15 rad. Those receiving 30 rad uniformly exhibited a reduction in lifespan, while the response in those receiving 15 rad varied. It is obvious, therefore, that this experiment with primary cosmic ray exposure is inconclusive, at least up to the 15 rad equivalent of primary exposure.

A thorough post-mortem examination was performed on each animal. Special attention was given to neoplastic processes, and for statistical reasons lung and mammary tumors were of chief concern. No significant difference in the incidence of lung and mammary tumors was observed between the experimental and control groups.

The study of the effects on reproduction was of secondary importance. Therefore, only elementary techniques were used for studying this portion of the experiment. The animals were subjected to a series of matings within their respective groups. The first mating showed approximately the same fertility rate in both the experimental and control groups. The second mating showed a lower average fertility in the experimental group than in the control group. Since the experiment was primarily designed to study longevity, serial sacrifices to determine pregnancy, resorption of fetuses, and other phenomena, could not be made. Consequently, the basis for the results could not be established.

3. Study of Integument

Black mice of the C-57 and AKF strains were exposed to primary cosmic radiation. One object of this study was to evaluate the changes in pigmentation and hair loss as indicators of the ionization path of the primary cosmic particles. Another purpose was to study the degree of permanency of the radiation damage to the skin per se.

Groups of black mice exposed on both 1954 and 1955 northern flights have been compared to mice carried on control flights from Holloman AFB. A significant increase in the number of white spots on exposed mice compared to controls was noted, as shown in Table IV (Ref. 2 and 3). Comparative studies revealed fewer white hairs on the mice exposed on the 1955 flights than on the 1954 series, although both were in excess of the controls (Ref. 2). Also observed on mice flown during the 1955 series, were streaks of white hair apparently caused by heavy nuclei penetrating the skin at an acute angle (fig. 25).

Several possible explanations have been presented concerning the greater incidence of white hairs on the mice exposed on the 1954 flights, compared to the 1955 flights. A greater oxygen partial pressure existed in the capsule environment of the 1954 flights which may have increased the biological effects of incoming primary particles (Table V). Another possibility is a variation in the type of particles present during the two flight series. Neutron counting rates for the two periods indicate similar primary flux intensities (Table VI). Recent data indicate that variation of int nsity of low energy particles could have occurred and not been detected by the neutron counters.

Yagoda (Ref. 32) observed the element distribution as recorded by nuclear emulsions on balloon flights on 18 and 19 August 1955. The ratio of medium to heavy nuclei, varied from 1.9 to 3.0 on these two successive days, while the total primary flux as measured by ground counters, varied less than one-half of one percent during the same period. See figure 26.

The wide streaks of gray hairs observed are also baffling (fig. 27). Supposedly, even heavy cosmic particles have a very small (4 - 6 microns) radial spread of radiation dosage high enough to cause hair graying. The streaks observed were up to 200 microns wide. Probably some indirect effect resulted in this wide path of damage. This could possibly be caused by circulatory damage to the distant melanin cells.

No immediate explanation is available for either of the preceding problems. Obviously a more complete monitoring system of the primary spectrum on each flight is necessary, as well as additional research on the exact mechanism of the biological effects produced by heavy particle paths.

TABLE IV

AVERAGE NUMBER OF WHITE SPOTS (SINGLES AND SMALLEST CLUSTERS) PER ANIMAL

From the 1954 and 1955 AMFL Flights with the corresponding calculated "hits" expected.

Flights	Duration/Animal. Altitude Range. (thousands of feet)	No. Animal Area/Each. Follicle Density	Average White Spots/ Animal	Diff. Exposed-Control (Net Av.)	Expected Av. Hits/Animal for 10,000 IP/μT	Expected Av. Hits/Animal for 2,000 IP/μT	Expected Flux of Primaries of All Energies/ Animal
1954 50, 51, 52 Saulte Ste. Marie	35.5 hours 82-97	40 (6, 25, 9) mice 10 cm^2 14 percent	13.8	10.6	0.2	13.4	331.6
1954 54 Control Holloman	24 hours 82-93	14 mice 10 cm^2 14 percent	3.2				
1955 63 Int. Falls	22 hours 96-124	52 mice 10 cm^2 14 percent	4.4	1.1	0.4	23.8	376.2
1955 Ground Control		42 mice 10 cm^2 14 percent	3.3				
1955 65 Int. Falls	23 hours 95-125	5 guinea pigs 100 cm^2 3 percent	0.8	0.8	0.8	51.4	794.2
1955 Ground Control		6 guinea pigs 100 cm^2 3 percent	0.0				
1955 66 Int. Falls	22.3 hours 78-95	69 mice 10 cm^2 14 percent	2.7	-0.6	0.1	5.8	157.4
1955 Ground Control		42 mice 10 cm^2 14 percent	3.3				

(a)

(b)

FIGURE 25. Comparison of White Spots Observed on (a) an Exposed Mouse, and (b) a Control Mouse.

TABLE V

CAPSULE OXYGEN PRESSURES

1954-1955 AMFL Balloon Flights

	Flight Number	Capsule Flush				Initial Phase				Time Hours	Flight Equilibrium Conditions			
		Oxygen %	Capsule Pressure in PSI	O_2 Pressure in PSI	N_2 Pressure in PSI	Total Capsule Pressure in PSI	O_2 Pressure PSI	N_2 Pressure PSI	O_2 Pressure Atmosphere	Capsule Closure to Equilibrium Conditions	Total Capsule Pressure PSI	O_2 Pressure PSI	O_2 Pressure Atmosphere	Duration Hours
1954 Flights	50	90	14.5	13.1	1.4	18.5	17.1	1.4	1.2	7	15.0	13.6	0.9	30.0
	51	90	14.5	13.1	1.4	19.5	18.1	1.4	1.2	7.5	14.5	13.1	0.9	30.5
	52	90	14.5	13.1	1.4	21.0	19.6	1.4	1.3	7.5	15.5	14.1	1.0	23.5
	54	90	14.5	13.3	1.2	20.5	19.3	1.2	1.3	8.0	15.0	13.8	1.0	24.0
1955 Flights	63	72	14.2	10.2	4.0	25.0	21.0	4.0	1.4	21.0	13.0	9.0	0.6	7.0
	65	50	14.2	7.1	7.1	22.0	14.9	7.1	1.0	17.0	12.5	5.4	0.4	12.0
	66	50	14.2	7.1	7.1	23.0	15.9	7.1	1.1	17.0	16.0	8.9	0.6	11.0

TABLE VI

NEUTRON COUNTING RATES INDICATING VARIATIONS
OF INTENSITY OF COSMIC RAY PRIMARIES*

1954 Flight Series Flight Number	Range of Counts per Hour	
	Climax D3A	Chicago E3B
46	1640-1668	397-427
47	1660-1691	386-411
49	1663-1684	386-416
50	1668-1698	373-402
51	1684-1707	381-412
52	1667-1683	396-417
53	1671-1709	399-419
Month	Monthly Average of Counts per Hour	
	Climax D3A	Chicago E3B
July 1954	1673.3	404.8
August 1954	1684.4	404.3
September 1954	1678.8	402.8
October 1954	1670.6	403.6

1955 Flight Series Flight Number	Range of Counts per Hour
	Climax D3A
61	1675-1699
62	1677-1694
63	1632-1662
64	1641-1688
65	1638-1673
66	1658-1681
67	1651-1681
68	1648-1668
70	1668-1691
Month	Monthly Average of Counts per Hour
	Climax D3A
July 1955	1668.7
August 1955	1663.6
September 1955	1672.0

* This information supplied by courtesy of Dr. J. A. Simpson.

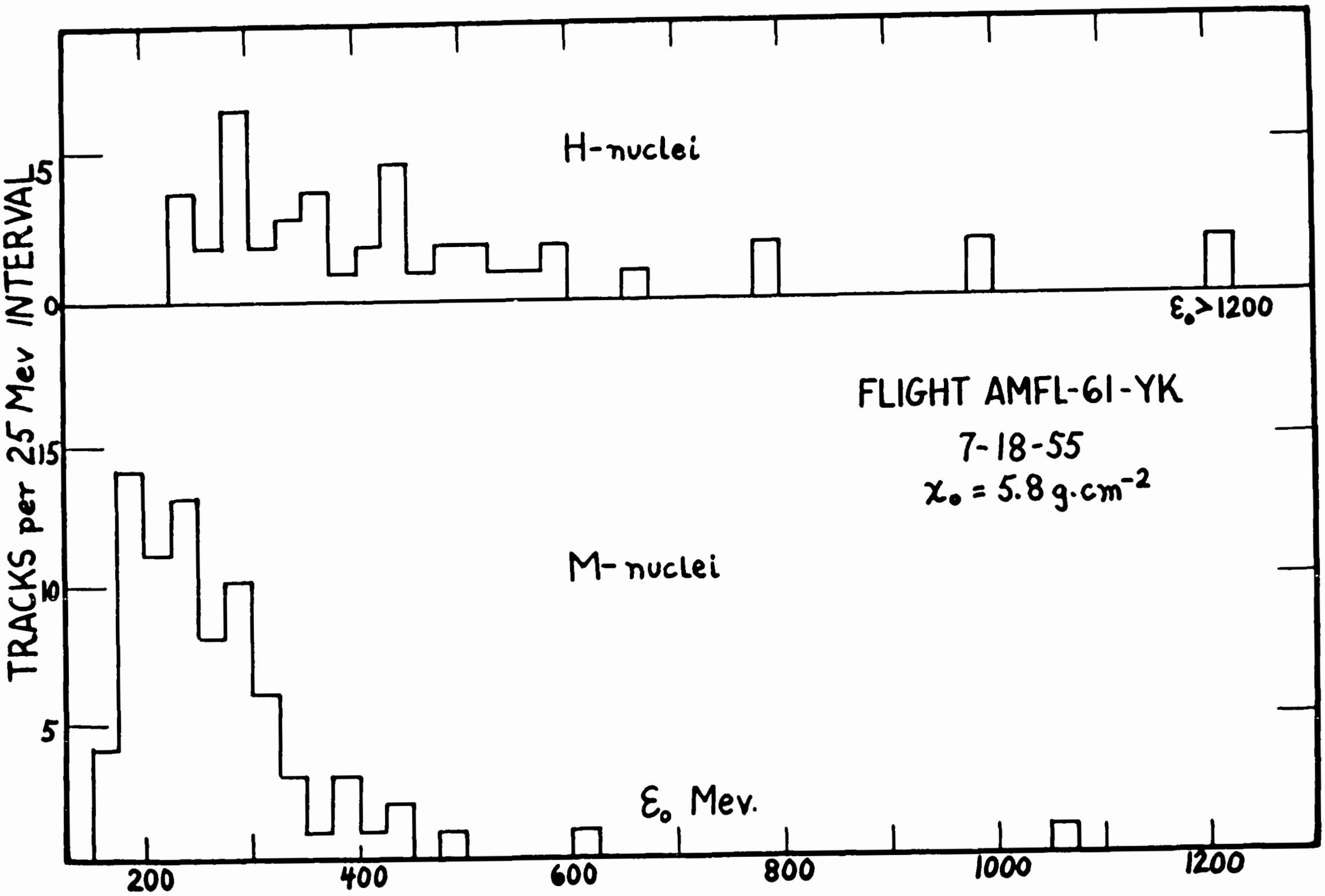


FIGURE 26. Relative Abundance of Medium and Heavy Cosmic Ray Primaries on Flight AMFL 61.

FIGURE 27. A Streak of White Hair Probably Caused by the Ionization Path of a Heavy Nucleus Striking the Skin Tangentially.

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Dr. Herman Chase of Brown University, under Air Force contract, performed cutaneous studies on mice using the heavy ion linear accelerator at Berkeley, California. These studies were aimed at determining the cutaneous RBE for heavy nuclei. Thirty-one mice were given doses from about 330 rad to 3000 rad. The skin damage observed, although shallow because the beam penetrates only about 270 microns, was tremendous. The first real skin burn and sloughing occurred at a dosage of 970 rad. Skin tension resulted in wound spreading, which gave the impression of a larger area of damage than actually occurred. This severe skin damage is an effect far beyond anything produced by X-rays at that dosage. Seven-millimeter areas were exposed, and exposure through 100 micron and less apertures is being planned.

4. Genetic Effects

The inseminated Drosophila melanogaster were flown for 15 hours above 90,000 feet at northern latitudes. The progeny of the 969 flies were examined for evidence of translocations. None were observed, but this finding is perhaps of little significance because of the statistically inadequate sample. Hit frequency calculations indicate that one would expect, at most, one heavy primary thin-down hit in the sperm storage areas (spermatheca) of the exposed group of flies (Ref. 19).

Eugster exposed dry corn and barley seeds on the 1954 and 1955 flights. He indicated that seeds exposed on the 1954 flights showing central (maximum ionization) hits were observed to produce dwarf forms.

Stone evaluated the preliminary experiments conducted with Neurospora samples on the 1955 flights. Eight tubes of specimens from Flight 61 showed no increase in the number of back mutants per 10^5 cells. Five of the nine tubes exposed on Flight 63, showed a significant increase in the number of back mutants. Two of the nine tubes from Flight 64 and three of eight tubes on Flight 67 were similarly positive. Since the controls of only one flight showed any positive tubes (two out of five) it would appear that a significant portion of the positive results observed among exposed specimens is caused by cosmic ray primaries. DeBusk (Ref. 5) examined Neurospora samples which he included on a high altitude MANHIGH test flight in April 1958, and found no increase of mutations in the exposed samples above those occurring in controls. Additional data are necessary to verify these preliminary findings.

Stone (Ref. 30) recently conducted a genetic experiment with Neurospora, using a heavy ion linear accelerator with which to obtain radiation exposure. This test was to study the back mutation rate caused by damage to one locus. Five reverse mutations were observed in some ten million cells exposed. No mutations were observed in three

million control cells. This may seem to be an extremely low mutation rate, but this test was only of one locus and there are perhaps two thousand different gene loci in Neurospora. Consideration given, the test parameters caused the mutation rate observed to assume much greater importance.

5. Neurocytological Effects

Several hundred slides from various experimental specimens have been examined for evidence of neurocytological damage caused by primary cosmic radiation.

Without an adequate monitoring system by which exact areas of entry by cosmic particles into the brain can be ascertained, the task of finding such an ionization track is formidable. Examination of histological sections revealed many suspicious areas which were labeled as artifacts, but no definite primary ionization tracks. Later flights were designed to have an adequate monitoring system so that precise hits and their angles of entry will be known, thus greatly enhancing the possibility of finding actual ionization tracks on histopathological examination.

The animal flights planned for the summer of 1958 included biological specimens monitored as described above. Unsuccessful attempts to launch the new 5,000,000 cubic foot balloon resulted in cancellation of the flight series.

One successful flight in the spring of 1957 contained several biological specimens which were monitored satisfactorily. A detailed discussion of the experiment follows. The principal investigator on this experiment was Dr. Webb Haymaker, Armed Forces Institute of Pathology, and the information included herein was compiled from reports by Dr. Haymaker (Ref 11).

A 3,000,000 cubic foot polyethylene balloon was used as the flight vehicle. The biological specimens (ten guinea pigs) were enclosed in a capsule capable of supporting life at extremely high altitudes for 24 hours and longer. The balloon was launched at 0718 CST on 14 April 1957 from South St. Paul, Minnesota. A maximum altitude of 103,000 feet was reached at 1020 CST and total hours above 100,000 feet altitude was 4 hours. A time-altitude chart for the flight is presented in figure 28. The balloon trajectory remained above 55 degrees geomagnetic latitude. At 1810 CST, the balloon landed near Saginaw, Michigan, and recovery of the capsule was effected immediately. Maximum temperature inside the animal capsule during the flight was 84°F.

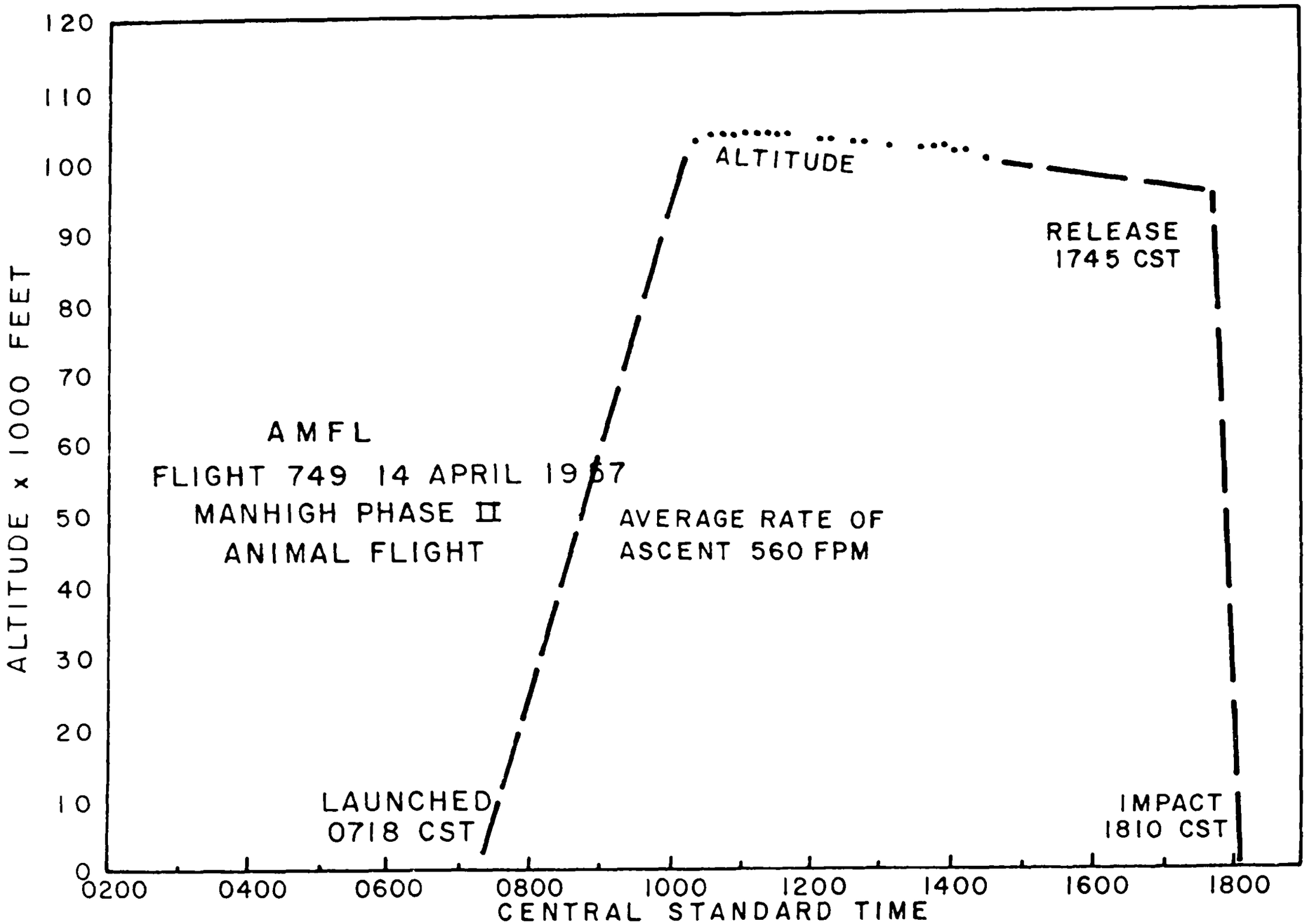

FIGURE 28. Time-Altitude Chart for MANHIGH Temperature Test Flight (14 April 1957)

a. Clinical Data on Guinea Pigs

Four of the animals were dead when the capsule was opened, but exact time or cause of death could not be established. The remaining six animals were taken by plane via Wright-Patterson AFB, Ohio, to the Armed Forces Institute of Pathology, where they arrived at 0930 EST on 15 April 1957.

The animals appeared a little depressed upon arrival at the Armed Forces Institute of Pathology, and each was given a penicillin injection. Three animals appeared somewhat dehydrated and were each given 100cc of physiological saline solution sub-cutaneously. Each animal was then placed in a separate cage.

The animals were sacrificed and prepared for examination according to the following schedule:

Guinea Pig No. 1 (AFIP acc. 799871) sacrificed at 1930, 16 April 1957

Guinea Pig No. 2 (AFIP acc. 799873) sacrificed at 1530, 17 April 1957

Guinea Pig No. 3 (AFIP acc. 799868) sacrificed at 1615, 17 April 1957

Guinea Pig No. 4 (AFIP acc. 799869) sacrificed at 1310, 18 April 1957

Guinea Pig No. 5 (AFIP acc. 799870) sacrificed at 1340, 18 April 1957

Guinea Pig No. 6 (AFIP acc. 799872) sacrificed at 1425, 18 April 1957

b. Description of Tests

The exact location of the nuclear track plates and holder with respect to the animal's head was achieved by means of X-rays. The nuclear emulsions were developed and read by Dr. Herman Yagoda of the National Institute of Health, Washington, D. C. The identification, position, and direction of primary cosmic ray paths in the emulsions were provided to Dr. Haymaker for use in localization of the paths in the brains. The guinea pig brains were extremely small targets. Tracks of heavy nuclei were found in practically all the plates, but none of these nuclei went through, or even grazed the brain. The heaviest primary particle having a trajectory through the brain of an animal was a medium weight nucleus, apparently neon, which traversed

the brain of guinea pig No. 1 (AFIP acc. 799871). Therefore, a heavy primary particle track through brain tissue was not available to identify in any of the animals in this experiment.

c. Technique Used in Sacrificing Animals

(1) The animals were given 0.2cc heparin (s.c.) and 0.2cc nembutal (i.p.). Next they were exposed to light ether anesthesia. The chest was opened and a canulla was inserted high in the aorta and tied. A clamp was put on the general region of the thoracic aorta. The right auricle was then incised. Approximately 75cc of perfusate was run through the head (and brain) and upper limbs. The brain was removed as quickly as possible and put into a fixative.

Perfusate:

Sod. Chloride	9.0 gm
Sacchorose	0.7 gm
Nitroglycerin solution (10 percent) dissolved in dilute alcohol	1.0 cc
Distilled H_2O	1000 cc

This mixture was put in a 150cc burette to which a 1.5 meter piece of polyvenyl tubing was attached.

Fixative:

Dioxane	89 cc
Glacial acetic acid	10 cc
Nitroglycerin solution (10 percent)	1 cc

After 48 hours the brains were transferred to 25 percent dioxane.

(2) Photographs were taken of each animal's head: (a) the top of the skull, and (b) the top of the brain.

(3) General autopsy was performed and the skull saved.

(4) The eyes were removed. In three animals (AFIP acc. 799868, 799871, 799873) the usual perfusion was carried out and the eyes were fixed in the solution mentioned. In the other three (AFIP acc. 799869, 799870, 799872) the eyes were removed before perfusion and fixed in the following solution:

1 part glacial acetic acid

3 parts 100 percent ethyl alcohol

After 48 hours removed to 60 percent ethyl alcohol.

d. Section and Staining Method

Once the site of traversal of the brain by a heavy primary was determined, the corresponding block of brain was removed and ten-micron thick serial sections were cut parallel with the projected course of the nucleus. An average of about four hundred sections per brain were prepared and stained by the Unna modification of the Van Gieson stain. Every fourth section was stained. This same sectioning and staining procedure was carried out in two control guinea pigs.

e. Results

(1) Guinea Pig No. 1 (AFIP acc. 799871). This animal was in the worst physical condition of the group. It did not eat, sat slumped, held head continuously to the right, but could walk. It was sacrificed at 1930 on 16 April 1957, approximately 56 hours after exposure.

The site of the estimated traversal of the brain by the cosmic nucleus (probably neon) was in the anterior part of the left hemisphere. Lesions were found in the right hemisphere; therefore, they did not correspond to the site of penetration of the identified particle.

The main lesion, as seen in cross section, consisted of a spherical focus of pronounced tissue sponginess (fig. 29). The border of the lesion in some of the cross sections had the very pronounced porosity characteristic of an early infarct. The lesion was located in the cerebral cortex. Some of the nerve cells in the focus were of normal size and had an exploded appearance, while others were extremely shrunken and hyperchromatic. Now and then a very shrunken nerve cell had numerous tiny condensed droplets or bulges along its surface, i.e., incrustation (cytoplasm which was extruding or had extruded through the cellular membrane), regarded as a sure sign of acute premortem cell death. A fair number of glia were irregularly shrunken and distorted. Two or three neutrophilic leukocytes were noted in the sheath of an occasional vessel. No clear-cut transudate of plasmatic fluid was found. The blood vessel seemed unaffected.

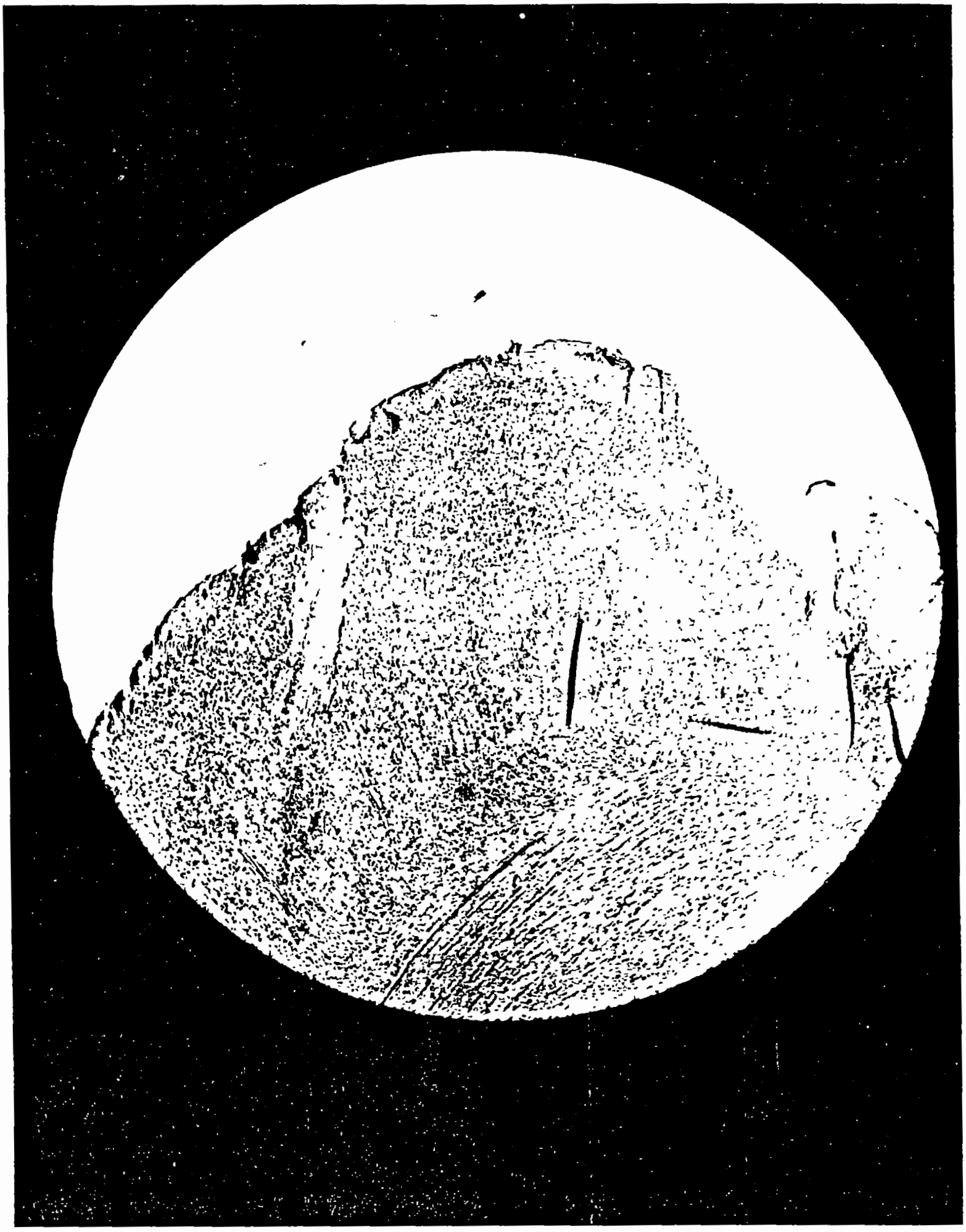

FIGURE 29. Typical Lesion Observed in Brain of Guinea Pig Exposed in MANHIGH Test Flight (14 April 1957).

The lesion was about 1000 microns long and 110 to 440 microns in diameter.

(2) Guinea Pig No. 2 (AFIP acc. 799873). This animal was in fair physical condition when it was sacrificed at 1530 on 17 April 1957.

No primaries were traced through the brain of this animal according to the attached nuclear emulsion. No alterations were noted on histological examination of the brain.

(3) Guinea Pig No. 3 (AFIP acc. 799868). This animal appeared depressed and it was felt necessary to sacrifice it at 1615, 17 April 1957.

The estimated course of four primary particles (probably of C, N, O group) through the brain was determined. Upon histological examination of the brain, no significant changes were observed.

(4) Guinea Pig No. 4 (AFIP acc. 799869). This animal remained in good condition until it was sacrificed at 1310, 18 April 1957.

The estimated course of a primary particle path (either nucleus of neon or oxygen) was determined. The projected path of this particle was in the right hemisphere of the cerebrum at a rather tangential angle with the brain surface. Upon histological examination of the tissue, no significant alterations were observed.

(5) Guinea Pig No. 5 (AFIP acc. 799870). This animal remained in good condition until it was sacrificed at 1340, 18 April 1957.

No primary particle paths were found in the monitoring nuclear emulsion which could be projected through the animal's brain tissue.

Histological preparation was carried out in the manner described in the paragraph on section and staining method. The microscopic examination of the sections was accomplished and no lesions or tissue alterations were observed.

(6) Guinea Pig No. 6 (AFIP acc. 799872). This animal also remained in good condition until sacrificed at 1425, 18 April 1957. The heart ceased beating approximately one minute before perfusion was done, and the efficiency of this procedure was therefore decreased.

The projected course of two primaries, estimated to be of the C, N, O group, was determined. One primary particle was

traced through the right cerebellum, the other through the right cerebrum. No lesions were found in the cerebellum on histological examination. Lesions were found in the right cerebrum. The lesions are similar to the one described for Guinea Pig No. 1. Most of them are spherical, while others have an irregular shape. Shrinkage and distortion of nerve cells and glia were more striking than in Guinea Pig No. 1. Nerve cell incrustation was of greater frequency. No edema fluid was seen, and if present while the animal was living, was of low molecular weight.

Measurements of the lesions in this brain varied from 110-1000 microns wide by 330-880 microns in length.

f. Discussion

The first point to be established is whether or not the changes described in the brains of Guinea Pigs No. 1 and 6 represent actual lesions. Dr. Haymaker states there is no doubt but that they are infarcts and not postmortem artifacts. Judging from the rather sparse nerve cell necrosis, much of the tissue damage may have been latent, with the lesions being made evident during the process of dehydration of the sections. Retraction of tissue elements in the development of the tissue porosity could have accounted for the exploded appearance of a good many of the nerve cells. Extreme shrinkage of nerve cells, and glia with nuclear distortion, were noted in both brains, indicating that cellular as well as tissue damage had occurred pre-mortem. Evidence of nerve cell death was very scanty, and included incrustation of occasional nerve cells. Here and there within lesions some small clumps of neutrophilic leukocytes were noted, especially in the brain of Guinea Pig No. 6. Exudation of such cells could occur only intra-vitam. Sparse ameboid (reactive) forms of glia were noted within the lesions, indicating that the pathological process had been underway for several hours.

Several factors indicate that the lesions do not represent cosmic ray tracks. The diameter of the lesions observed ranged from 110 to 1000 microns in width. Computations by Dr. Herman Yagoda reveal that a single iron nucleus should produce tissue damage not more than 90 microns in diameter. The heaviest primaries observed in the monitoring nuclear emulsions were in the range of neon. Thus, unless some unknown mechanism caused an increase in tissue damage, the diameter of the lesions was too large to represent single particle tracks. In one animal (Guinea Pig No. 1) the lesion observed was not in the part of the brain that it should have been according to the monitoring nuclear emulsion, while in Guinea Pig No. 6 the lesion did correspond to the projected path from the emulsion. It is possible that a particle could have entered the brain of Guinea Pig No. 1 without traversing the monitoring emulsion. Nevertheless, the discrepancy between the path observed in the emulsion and the lesion observed in Guinea Pig No. 1 casts uncertainty on the cause of the lesions.

The lesions are believed to be caused by focal ischemia. It is seen under numerous conditions, such as gas bubble emolization, irradiation of the brain, and in head-body irradiation associated with anemia. The lesions observed definitely occurred prior to death and known causes for focal ischemia could not be attributed to their cause (Ref. 11). It is felt that cosmic radiation was a possible factor in the production of the lesions observed, but the lesions being nonspecific make such a theory very vulnerable to criticism. Not until there is an opportunity to study more monitored brains, especially ones traversed by heavy primaries, can a reliable answer be provided concerning the neurological damage, if any, of heavy cosmic ray primaries.

6. Developmental Effects

Ten groups of radish seeds with approximately 500 seeds per test tube were given cumulative exposure on from one to eight flights. Several experiments utilizing various groups of these seeds have been performed. The results of the principal experiment using seeds with the greatest total exposure (eight flights), and controls (Ref. 13), which were exposed in an altitude chamber to conditions of temperature, pressure, and humidity similar to those encountered on the flights, indicated that there were no significant differences in the dry seeds which could be interpreted as resulting from exposure to primary cosmic radiation (Ref. 24).

These seeds had a total exposure of 251.1 hours in the region of primary cosmic radiation above 82,000 feet. Thus, these data serve to increase the probability that there are no unexpected or unusual effects of exposure at these altitudes. The frequency of thin-down hits with an ionization of 10^4 ion pairs per micron of path through tissue, is sufficiently high (approximately 10 percent of the seeds are hit) to suggest that, for this test system, there is no abnormally high relative biological effect of these thin-down events.

The hen eggs used in developmental studies proved to be an impractical specimen because of their inability to withstand the rigorous environmental conditions imposed by the balloon flights. None of the exposed chicken eggs developed.

The fetal mice showed a very high intrauterine mortality rate not considered attributable to radiation effects, but probably caused by sustained high oxygen tension.

The studies conducted by Dr. Walton on snapdragon seeds, grasshopper eggs, and onion seeds, were interrupted because of his untimely death. Preliminary data indicated that developmental aberrations attributable to cosmic ray primaries would have been observable

among the grasshoppers. Both types of seeds flown wet showed a higher sensitivity to cosmic radiation than the corresponding seeds flown dry.

7. Ophthalmological Effects

Forty-nine mice exposed on various flights listed in Table I were examined 24 hours after their return to the principal investigators, and at intervals of 14 to 21 days thereafter for 3 months. Thorough examinations revealed no evidence of lens damage.

Hit probabilities were calculated for the total volume of the eye, to provide information concerning the limiting situation. The sensitive volume for radiation-induced cataract changes is certainly less than the total volume of the eye. There are variations, even within the volume of the lens, with the very small nuclear zone having the greatest sensitivity. The hit probability that 1 hit and 900 traversals by primary particles of $Z \geq 7$ will occur in the lens volumes of 30 mice during a 30-hour flight, indicates cosmic radiation is not inordinately effective in producing lens opacities (Ref. 24).

VII. CONCLUSIONS

Studies concerning the biological effects of primary cosmic radiation are indeed complex and present innumerable problems. The physical characteristics of the primary particles are not completely understood. Their intensity varies with geomagnetic latitude and with altitude; and superimposed on this variation is the intensity and spectrum variation with time. Because of the preceding particle intensity and spectrum fluctuations, an excellent physical monitoring system is very desirable, if not a necessity, in order that accurate radiation exposures may be ascertained. Except for the low Z primaries with low energies, the primary cosmic particles cannot be reproduced in laboratories. This presents another problem - one of obtaining primary cosmic radiation exposures.

Stratosphere balloons were used as the method of obtaining this exposure in all the cosmic radiation studies included in this report. Flying live biological specimens at extremely high altitudes for several hours was a new venture and posed many challenging problems. A capsule system, capable of sustaining life in a completely hostile environment, had to be devised. Balloon launching, tracking, and recovery techniques had to be perfected. As a result of the many and varied problems presented in the cosmic radiation studies, many early flights were of necessity largely designed to perfect techniques (Ref. 23). Indeed, even later flights were largely experimental, since unforeseen difficulties arose, resulting in non-completion of the primary flight mission.

Prior to the studies accomplished by this laboratory, very little high altitude research on the radiobiology of primary cosmic radiation had been accomplished. The rapidly approaching era of space flight made such studies imperative. Since about 1950 and 1951, the efforts directed toward discovering the biological effects of primary cosmic radiation have increased many-fold; yet much research remains to be done before the effects and modus operandi of these primary particles are adequately understood.

From the experiments conducted by this laboratory several conclusions can be drawn.

The cutaneous studies resulted in the observation of positive effects of primary cosmic radiation. Repeated observations of significant increases of gray hairs on exposed mice and guinea pigs over control animals are interpreted as areas of penetration by heavy primaries. Observation of several gray streaks 200 microns wide suggests that an unidentified mechanism causes a much wider radial spread of heavy primary radiation effects than was anticipated. The 200 micron wide streaks evidence a radial spread of ten times larger than was expected. Several possible causes for this large radial spread have been suggested: (1) distant migration of toxic products, (2) vascular damage, and (3) some radiobiological mechanism not previously observed. None of these possibilities have been explored and more studies must be conducted to provide an answer. Cutaneous studies with 250 kv X-rays indicate that the hair pigment cells must receive at least 100 roentgens before gray hairs result. Consequently, damage at least equivalent to that incurred by 100 roentgens of 250 kv X-ray must have occurred over a 200 micron wide path.

Neurocytological studies have not resulted in a known observation of a cosmic particle path. One suspected lesion has been discussed in another section of this report. X-ray studies of neurological tissue indicate that nerve cells are injured but may not be killed by radiation doses of 20,000 to 50,000 roentgens. Calculations by Schaefer indicate that only the central one to two micron diameter core of a heavy primary track reaches ionization intensities of this magnitude. Radial spread of damage may be much larger as indicated by the cutaneous studies; however, because of the high resistance of nerve cells to radiation, only reversible damage may result from radiation intensities characteristic of heavy primaries. Any damage to the vascular system that might be produced could probably be fully compensated for by collateral circulation.

The negative results obtained thus far suggest that cosmic ray primaries do not destroy a path of nerve cells as large as that observed in cutaneous tissue. Additional experiments, with completely monitored biological specimens, should clarify the extent of neurological damage by cosmic ray primaries.

Preliminary developmental studies suggest germinating seeds are more radio-sensitive than dry ones. Carefully monitored experiments of this type should provide very helpful quantitative data. The reports by Eugster of marked reduction in hatching rates of Artemia salina caused by cosmic radiation suggest further investigations in this area.

Genetic experiments by Stone and DeBusk indicate a genetic hazard of unknown degree. Preliminary laboratory studies with the Heavy Ion Linear Accelerator (HILAC) have been conducted with positive results observed. Additional experiments with the HILAC should provide excellent quantitative data, and a satisfactory genetic Relative Biological Effectiveness (RBE) for heavy charged particles may evolve.

The most obvious conclusion derived from these studies is the dire necessity for additional research in primary cosmic radiation. New techniques have evolved and the need for others can now be visualized. More data are becoming available concerning the physical properties and intensity and spectral fluctuations of primary cosmic radiation.

Both positive and negative results obtained to date must be re-evaluated, using these new techniques and this additional knowledge.

True, studies accomplished indicate that no significant biological damage ensues from 24 to 48 hours of exposure to primary cosmic radiation, but the era is rapidly approaching when man will spend weeks and even months in space. The biological hazard of exposure to space radiations for such periods of time is not known; indeed, it has not even been explored. The cosmic radiation studies conducted by the Aeromedical Field Laboratory and others can only serve as a stepping stone to more extensive research on hazards of space radiation.

VIII. RECOMMENDATIONS

A. Biological Studies

1. Efforts expended on experiments which proved impractical, (hen eggs, pregnant mice) indicate that laboratory studies should be emphasized using microbeams of stripped nuclei to simulate primary cosmic radiation. These studies should design and evaluate experimentation directed toward determining the biological damage caused by heavy nuclei and their method of action to cause this damage.

2. After evaluation of experimentation by ground laboratory studies, actual primary cosmic particle exposure should be accomplished by use of stratosphere balloons to obtain quantitative data. Although satellites offer a better method of exposure, cost prohibits their use in preliminary investigations.

3. To obtain maximum primary cosmic ray exposure without influence by the atmosphere of the earth, final experimentation should be effected through the use of bio-satellites.

B. Physical Cosmic Particle Studies

1. Unexplained variations in results obtained (cutaneous studies), and the necessity for correlating observations with specific physical exposure, indicate that all biological experimentation using actual primary cosmic particle exposures must be adequately monitored. This should include nuclear emulsion monitoring of the specific specimens when possible, plus complete monitoring of cosmic ray charge, energy, and intensity during exposure.

2. The charge and intensity spectral variations of primary cosmic particles should be studied. Special emphasis should be placed on low energy (< 1 BEV/nucleon) heavy ($Z \geq 6$) nuclei. This is borne out by the relative lack of data in this area and the great potential radiobiological hazard of low energy heavy nuclei.

REFERENCES

1. Campbell, Berry, "Research on the Biological Effects of the Heavy Particle Cosmic Rays," HADC-TR-55-8.

2. Chase, Herman B., and Janice S. Post, "Damage and Repair in Mammalian Tissues Exposed to Cosmic Ray Heavy Nuclei," J. Aviation Med., 27:533 (December 1956).

3. Chase, Herman B., Janet D. M. Bliss, William E. Straile, and Janice S. Post, "Effects on the Skin by Cosmic Ray Heavy Particles," HADC-TR-55-2.

4. Chase, Herman B., "Cutaneous Effects of Primary Cosmic Radiation," J. Aviation Med., 25:388 (August 1954).

5. DeBusk, A. Gib, Personal Communication.

6. Dubs, C. W., Cosmic Radiation, Handbook of Geophysics for Air Force Designers, Air Force Cambridge Research Center, USAF.

7. Ellis, R. A., Jr., M. B. Gottlieb, and J. A. Van Allen, "Low-Momentum End of the Spectra of Heavy Primary Cosmic Rays," Physical Review, 95:147 (July 1954).

8. Eugster, J. A. G., "Effects on Living Tissues by Primary Cosmic Radiation," AFOSR-TR-56-19.

9. Eugster, J. A. G., Weltraumstrahlung, Bern: Hans Huber, 1955.

10. Foelsche, Trutz, "Estimate of the Specific Ionization Caused by Heavy Cosmic Ray Primaries Along Their Path in Tissue or Water," AFMDC-TN-59-7, April 1959.

11. Haymaker, Webb, Personal Communication.

12. Harlow, Harry F., Allan M. Scheier, and David G. Simons, "Exposure of Primates to Cosmic Radiation Above 90,000 Feet," J. Comp. and Physiological Psychology, 49:2 (April 1956).

13. Longmore, W. J., "Preparation of Control Specimens for the 1954 Aeromedical Field Laboratory Balloon Flights," HADC-TN-55-6.

14. Schaefer, Herman J., "Exposure Hazards from Cosmic Radiation Beyond the Stratosphere and in Free Space," Res. Rept. U. S. Naval School of Aviation Medicine, Pensacola, Florida, March 1952.

15. Schaefer, Herman J., "Graphs and Tables for the Hit Frequencies from the Heavy Nuclei of the Primary Cosmic Radiation," Research Report NM001 101 100 No. 13, U. S. Naval School of Aviation Medicine.

16. Schaefer, Herman J., "Theory of Protection of Man in the Regions of the Primary Cosmic Radiation," Project Report No. NM 001 059.13.06, U. S. Naval School of Aviation Medicine, 1953.

17. Schaefer, Herman J., "Graphs and Tables for the Hit Frequencies for Small Specimens (Drosophilis, Plant Seeds, Etc.)," Project Report No. NM 001 059.13.08, U. S. Naval School of Aviation Medicine, 1954.

18. Schaefer, Herman J., "The Rate of Energy Loss (REL) in the Terminal Section of Heavy Nuclei Tracks in Living Tissue," Progress Report No. NM 001 059.13.05, U. S. Naval School of Aviation Medicine, 1953.

19. Simons, David G., "Biological Effects of Primary Cosmic Radiation," paper presented at VIIth International Astronautical Congress.

20. Simons, David G., and D. P. Parks, "Improved Technique for Exposing Animals to Primary Cosmic Ray Particles," J. Aviation Med., 27:1.4 (August 1956).

21. Simons, David G., chapter in Biological Hazard of Space Radiations, 3d Edition, Otto Glasser, ed.

22. Simons, David G., "Surface Temperatures of Animal Capsules Floating Above 80,000 Feet," HADC-TR-56-6.

23. Simons, David G., "Stratosphere Balloon Techniques for Exposing Living Specimens to Primary Cosmic Ray Particles," HADC-TR-54-16.

24. Simons, David G., and C. H. Steinmetz, "The 1954 Aeromedical Field Laboratory Balloon Flights - Physiological and Radiobiological Aspects," J. Aviation Med., 27:100 (April 1956).

25. Simpson, J. A., "Solar Origin of Changes in the Primary Cosmic Radiation," Proceedings of National Academy of Sciences, Vol. 43:1, pp 52-56 (January 1957).

26. Simpson, J. A., "The Cosmic Radiation and Solar-Terrestrial Relationships," Extrait des Annales de Geophysique, 11:305 (1955).

27. Singer, S. F., "Effects of Interplanetary Dust and Radiation Environment on Space Vehicles," 2nd International Symposium on the Physics and Medicine of the Atmosphere and Space.

28. Steinmetz, C. H., "Experimental Material Flown on Aeromedical Field Laboratory Balloon Flights 46 Through 71," HADC-TN-56-2.

29. Steinmetz, C. H., "Techniques Used for Monitoring Biological Specimens on the 1954 and 1955 Aeromedical Field Laboratory Balloon Flights," HADC-TN-57-1.

30. Stone, Wilson S., Personal Communication.

31. Upton, A. C., "Ionizing Radiation and the Aging Process," J. Gerontology, 12(3), 306-313 (July 1957).

32. Yagoda, H., "A Study of Cosmic Ray Heavy Primary Hits in a Phantom of the Human Brain," Extrait des III Congress International de Neuropathologia, Brussels, Belgium.

33. Yagoda, H., "Frequency of Thindown Hits by Heavy Primary Nuclei in Emulsion and Tissue," J. Aviation Med., 27:522 (1956).

APPENDIX

RADIATION HAZARDS IN SPACE FLIGHT

by

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APPENDIX

RADIATION HAZARDS IN SPACE FLIGHT

I. INTRODUCTION

In a previous review (Ref. 1), the author evaluated the intensity of cosmic radiation near the top of the atmosphere, in order to estimate the hazards involved to aviators, and found that even with intense daily flights, the radiation exposure remains below the permissible limit.

During the past five years, potentialities of space travel have greatly increased and new knowledge has become available regarding the nature of cosmic radiation. In this report the knowledge pertinent to dose evaluation is reviewed for conditions of flight in space in the vicinity of the earth, but away from the influence of its atmosphere or magnetic field. Certain properties of the heavy nuclei are also discussed, as well as some of the available information on their actual biological effects. Development and completion of the new Heavy Ion Linear Accelerator allows extension of quantitative biological work with these particles. Finally, the statistical nature of the hazard from cosmic radiations, and the limitations of space flight caused by such rays are discussed.

II. THE PRIMARY COSMIC RADIATION

Our present picture of the primary cosmic radiation is that of a sea of rapidly moving nuclei, stripped of their electrons and converging incessantly on the earth homogeneously from each direction in space. Protons are most abundant, while the frequency of particles diminishes with increasing atomic number. Neutrons, electrons, and gamma rays are largely absent; at least they are not found in the primary component near the top of the atmosphere.

The observed intensity and energy distribution of the rays at ground level and high altitude, is not necessarily a true reflection of what one might find in space away from the earth, since the particles at the low energy end of the spectrum are deflected by the earth's magnetic field and by magnetic fields external to the earth. An observed spectrum of heavy primaries, as measured by Danielson et al. (Ref. 48) is given in Figure 30. Data are not given near the north pole, where measurements in different years have very different results. Ellis et al. (Ref. 3) have shown that the cut-off in low energy particles is caused by a magnetic field not due to that of the sun or the earth, and in the last twenty years it has become increasingly clear that low energy nucleon components of the primary cosmic rays show great variations.

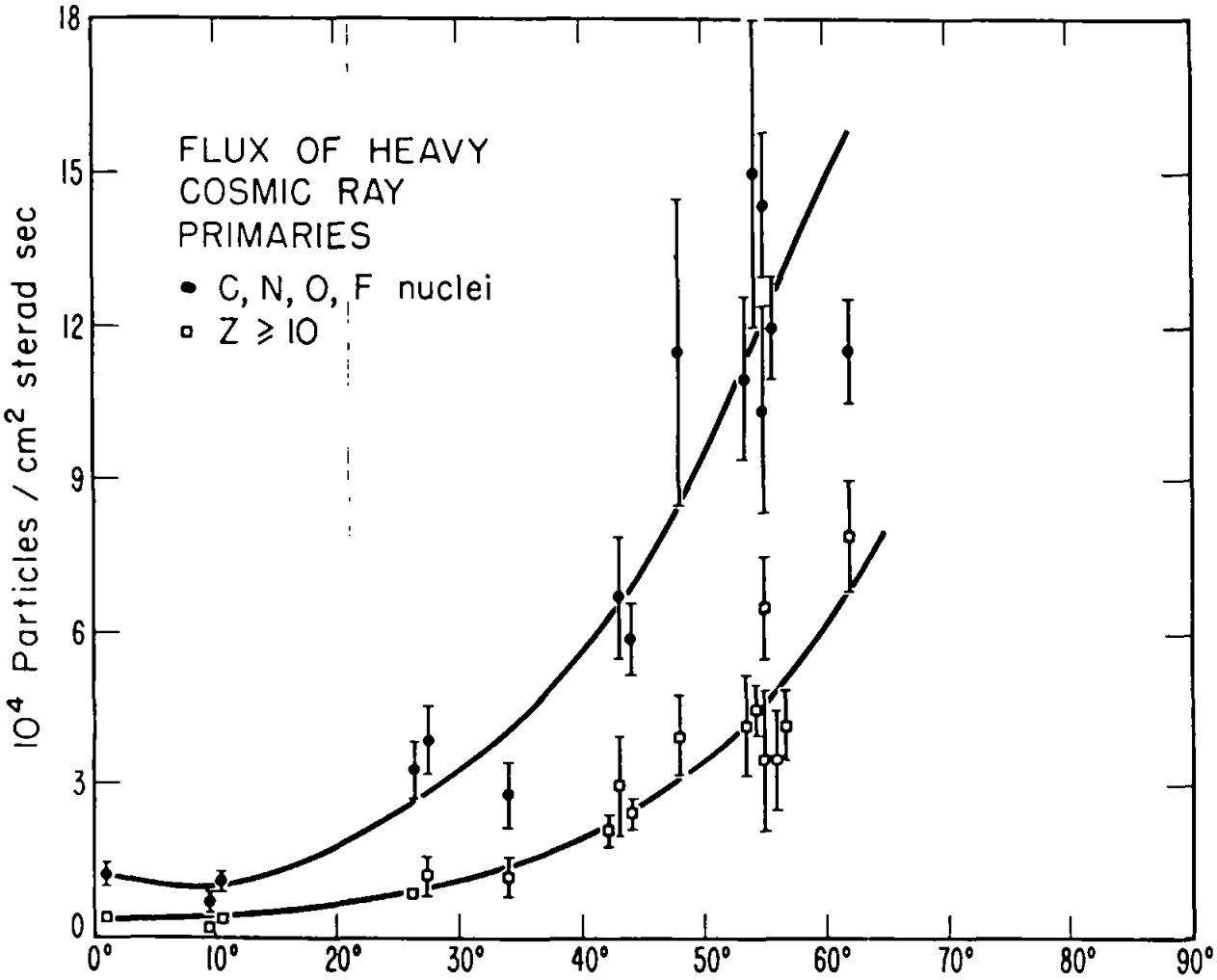

FIGURE 30.

Flux of Heavy Cosmic Ray Primaries as Function of Geomagnetic Latitude Corrected According to a Method Proposed by Simpson. Data by Danielson, Freier, Naugle, and Ney (Ref. 48).

From the isotropic distribution of the primary rays, it seems clear that the majority of them must originate outside of the solar system, and in order to explain their presence one must propose a satisfactory injection and acceleration mechanism, as well as one for elimination of some of the particles. We know several types of stellar events that involve emission of ionized matter into space. Fermi (Ref. 4 and 7) suggested that collisions of particles with ionized magnetic clouds can cause their acceleration. From general considerations of energy density in space, it is now believed that most of the cosmic rays within our galaxy originate here and are contained within it (Ref. 5) by virtue of the magnetic fields at the edge of the galaxy. The particles may have a mean life of perhaps 10^8 years before they escape into intergalactic space. The strongest sources of cosmic rays in our galaxy are believed to be the radio stars, many of which are located near the center of the galaxy (Ref. 6).

The level of cosmic radiation is governed by the equilibrium between the generating process and the escape process and locally on the presence of magnetic activity resulting from cosmic clouds. The above outlined principles predict an energy distribution for the primaries in agreement with the experimentally found distribution at high energies per nucleon (above several BEV/nucleon). If N(E) be the number of particles in energy range dE

$$\frac{dN}{dE} = -E^a \qquad \text{where } a = -1.8$$

This relationship is followed up to the highest primary events:

$E \sim 10^{18}$ ev. Knowing the distribution of cosmic ray primaries over the surface of the earth and their dependence on energy, Rossi (Ref. 8) states that the energy flux of cosmic radiation in the neighborhood of the earth is

$$3.5 \times 10^{-3} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ ster}^{-1}$$

and that cosmic ray energy density in space is

$$1.4 \times 10^{-12} \text{ erg cm}^{-3} \sim 1 \text{ ev cm}^{-3}$$

These figures correspond to about

$$7.2 \text{ primary particles cm}^{-2} \text{ sec}^{-1}$$

and to dose level of about 25 millirad per day.*

This latter figure is about twice the dose one receives at geomagnetic latitude of the United States near the top of the atmosphere (Ref. 1). There are so many uncertainties in the calculation that the figure may be off by a factor of two.

A. Variation in the Cosmic Radiation

Over the last twenty years important spatial and temporal variations in cosmic ray intensity and energy distribution have been detected. These are important in radiation studies not only because they are necessary for evaluation of the dose, but also because they should be correlated to results of balloon and rocket flight tests of biological specimens.

B. Solar Flares

The most spectacular changes in the primary component of cosmic radiation are those associated with solar flares. The events briefly accounted are as follows: a region of the solar chromosphere having an area of a few ten-thousandths of the solar surface starts intense light emission. The luminosity of the flare increases greatly for a period of two to three minutes, then gradually decays with a mean life of about one half hour. Radio waves are received with slight delay. Primary cosmic rays rise to a maximum about one hour after the light flash and decrease to normal within a day. The flare is followed one to two days later by an intense magnetic storm and frequently a concomitant decrease in cosmic ray intensity.

Five important solar flares have been recorded during the past 15 years (Ref. 9).** During the last important solar flare (Ref. 10)

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* 1 rad = 100 ergs g^{-1}; 24-hour day.

** 28 February 1942; 7 March 1942; 25 July 1946; 19 November 1949; and 23 February 1956.

there was an increase of as much as thirty-fold in neutron intensity (Ref. 11) within fifteen minutes, reflecting similar increases in the primary particles (at 54°N, 71°W) whereas mesons only increased 58 percent (Ref. 10). The increase in the primary low energy component, up to 4 BEV/nucleon, was much greater than that in the high energy part of the spectrum. One of the most interesting aspects of cosmic ray increases after solar flares is that the rays strike the earth in very uneven distribution. Firor (Ref. 12) calculated the probable zones of impact of cosmic rays on the earth in the energy range of one to ten BEV and found that if the particles come from the sun, then, due to deflecting influences of the earth's magnetic field, some zones receive more dose than others. Geomagnetic latitudes between 25 and 60 degrees exhibit an increase, while equatorial and polar zones should remain relatively free of change. A good part of the North American continent falls in the heaviest irradiated zone. Existing data on the geographical distribution of the flare-type increases bear out the theoretical predictions; and thus we are now quite certain that the particles arriving associated with the solar flares do originate in the sun and are accelerated in a reasonably direct manner. When man has learned to fly at a distance of one or more earth diameters away, he should experience the full, undeflected intensity of the solar flare particles in each direction, in some locations reinforced by the albedo (reflections) from the earth's magnetic field. It also seems reasonable that should one attempt to fly closer to the sun than we are at present, the cosmic rays of solar origin should increase in intensity at least as fast as the inverse square distance law would predict. Now a high primary radiation intensity in prolonged flight or in residence on one of the planets, may make serious limitations on life span and evolutionary processes. Thus, solar cosmic rays should be considered in the definition and limitations of Strughold's Helioecosphere (Ref. 13). Contributions of solar flare doses of cosmic rays to the average dose level at ground level, or at high altitudes, are not significant. The quantitative observations have been too recent, however, to predict what variation in the size of solar flares we may expect in times to come.

C. Cosmic Ray Increases with Small Solar Flares

Simpson et al. (Ref. 14) found that numerous small solar flares correlate with increases in the primary cosmic radiation as observed by neutron changes. Again the increases are attributed to generation of rays by the sun.

Direct measurements on the time variation of the primary nucleon component of cosmic rays near the top of the atmosphere are difficult to perform, and ever since the detection of the heavy nuclei there have been doubts as to the nature and magnitude of some variations. In an ingenious experiment, Koshiba and Schein (Ref. 15) investigated the time variations of $Z > 10$ nuclei at an altitude of 100,000 feet. They found

an amplitude variation of about 35 percent within a few hours elapsed time. Their experiments give good indication of the difficulties of correlating biological changes in balloon flights to cosmic ray spectrum and intensity. It seems imperative that the physical and biological measurements be done simultaneously.

The increases of cosmic radiation which correlate to solar flares are the only ones which seem to be caused by direct production of the rays by the sun. For all other sun-correlated intensity changes, Morrison (Ref. 16) suggested a common cause; time and energy modulation of the incoming galactic cosmic ray beam by random diffusion, and deflection of the particles through turbulent clouds of ionized plasma emitted by the sun. Among such events are the sporadic decreases of overall intensity of cosmic rays arriving at the terrestrial surface. These were discovered by Forbush (Ref. 17) during intense magnetic storms. Other such variations are the 27-day recurrent minima in the cosmic ray intensity and 11-year variation of the primary particle spectrum and intensity.

D. Magnetic Storms

Intense magnetic storms usually follow solar flares by about a day. Since 1936 (Ref. 33), violent solar flares have been seen (Ref. 23), which resulted in definite decreases in cosmic ray intensity of about 5 percent in the ground level meson component, and approximately 25 percent in the primary nucleon component. All this change is in energy interval 0 to 5 BEV/nucleon. It usually takes 5 to 10 days for the intensity to return to normal. The magnetic storms may signify passage across the earth of a turbulent ion cloud which originated in the solar flare. Such a cloud disturbs and sweeps out many of the electrons from the Heaviside layer and can cause the well-known northern lights. The abundance of very low-energy particles in these clouds is not known; neither do we have sufficient information about whether or not they significantly contribute to dose.

E. Twenty-Seven Day Cycle of Variation

Another type of solar cosmic ray variation is correlated with the sun's rotation period of 27 days (Ref. 18). This effect amounts only to approximately 3 percent for the low energy nucleon component and 0.5 percent for the meson component. It is not regular and its study is made difficult by the superimposed fluctuations and different kinds of variations. There is some evidence that cosmic ray maxima occur within about a day after the central meridian passage of a magnetic monopole region (sunspot) in the chromosphere of the sun, and Morrison assumed that this region of the sun initiates a magnetic region in space into which low energy cosmic rays diffuse with ease.

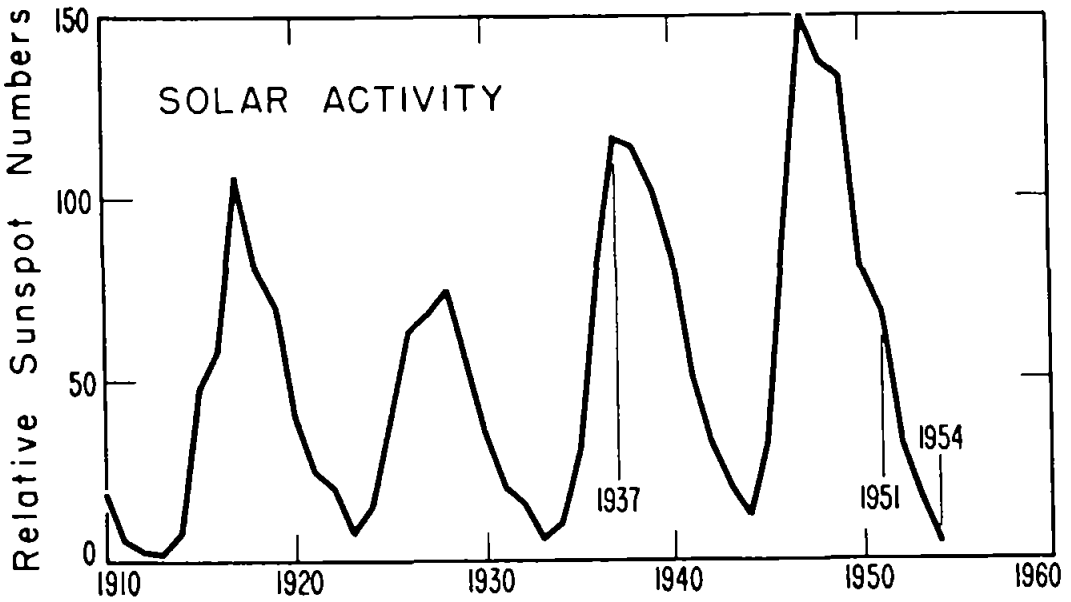
F. Eleven-Year Variation

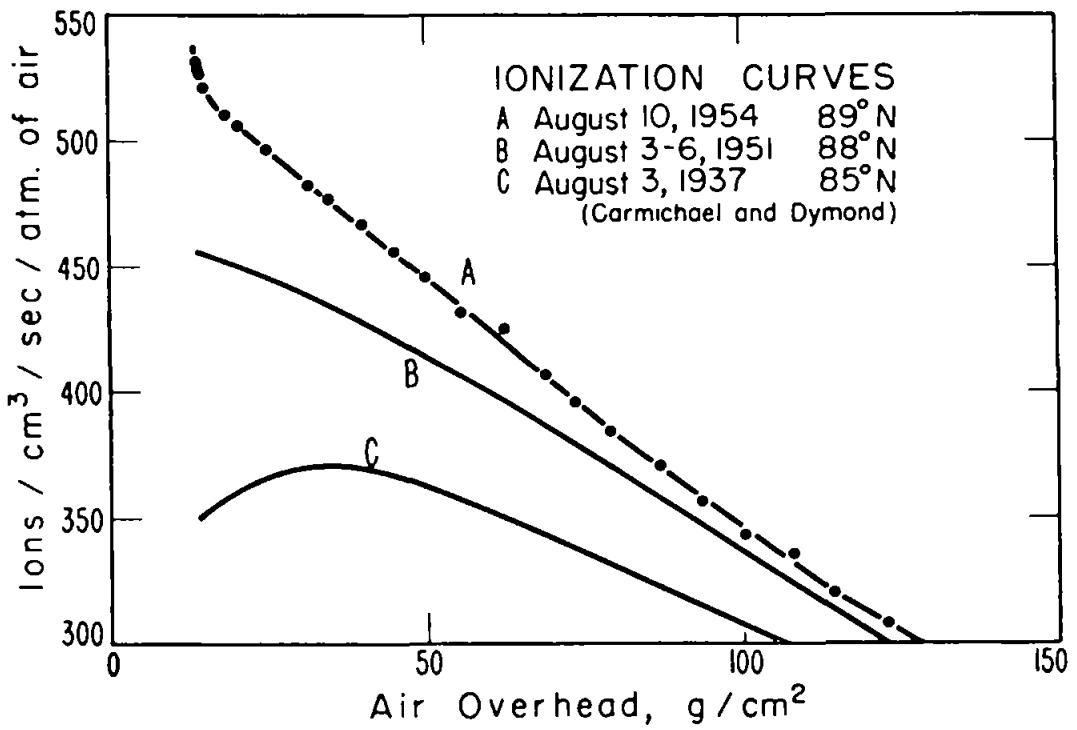
The most interesting glimpse into the energy spectrum and intensity of primary cosmic radiation is given by the 11-year solar cycle. This is usually interpreted in terms of overall sunspot activity reflected by numerosity and intensity of terrestrial magnetic storms. Forbush (Ref. 17) demonstrated that low sunspot activity is accompanied by high cosmic ray intensity, and high sunspot activity by low intensity. Examples of these variations were given by Neher (Ref. 19), who compared measurements of ionization of primary particles in the years of 1937, 1951, and 1954. Figure 31 indicates measurements near the magnetic north pole on the three occasions. In 1937 the sunspot activity was maximum, and the ionization minimum; in 1954 the sunspot activity was minimum and the cosmic ray ionization above the geomagnetic north pole more than doubled. In 1951, a year of medium sunspot activity, the cosmic rays were at a level considerably higher than in 1937.

In years of high sunspot activity, primaries of low energy are not admitted, but in years of low activity these can arrive at the surface of the earth in regions where the earth's own geomagnetic field permits (near the poles). In 1951 the increase over the minimum was mainly due to particles between 1.5 and 4 BEV/nucleon; in 1954 the protons of lower than 1.5 BEV and perhaps other particles of similar magnetic rigidity increased significantly. From the solar maximum to the minimum, the energy being brought to the earth by cosmic rays increased by 14 percent. The number of incoming particles increased by a factor of more than 2.4. The dose increased by an even greater factor than 2.4.

The presence of low-energy particles near the north pole does not materially affect the safety considerations for flying for temporary periods in the temperate and warm zones up to 200,000 feet. We should be prepared, however, to find in true space flights a higher dose rate, such as one finds at high altitudes over the magnetic poles in years of low sunspot activity. Much more exploration is needed in the low-energy region to know the exact dose rate, and great variations are expected from magnetic clouds and solar eruptions.

Looking back to the history of the universe, Teller (Ref. 20) makes the suggestion that the overall intensity of the galactic component of cosmic rays may have significantly altered at times in the past. If by explosion of a nova, or some other process, a new radio star were to be formed on the same bundle of magnetic lines of force which pass through the solar system at a distance of perhaps 1,000 light years or less from our own location, then a great increase of cosmic ray intensity could be expected. We know that such events do occur, and by watching the sky we may have advance notice of them. An increase of cosmic ray levels by a factor of 1000 might lead to increased mutation rate and enhanced multiple mutation frequency. It is well known





Redrawn from H. V. Neher, Physical Review, 103:228 (1956).

FIGURE 31.

Upper Graph: Solar Activity as Measured by the Relative Sunspot Numbers.

Lower Graph: Ionization Curve Near the Top of the Atmosphere near the Geomagnetic North Pole for **Three** Different Years. (1954, sunspot minimum; 1937, sunspot maximum; 1951, medium activity.)

that in the course of evolution of the species as yet unexplained gaps exist where intermediate living forms are missing. The cosmic increases mentioned may account for the apparently anomalously rapid evolutionary epochs. One must admit, however, that at the present time we do not attribute more than 10 to 15 percent of natural mutation rate to radiation, and temperature increases or changes in chemical environment can also lead to increased mutation rates. From radiocarbon dating it appears as though during the last 20,000 years there has been no very important increase in cosmic ray intensity.

III. METHODS OF OBTAINING KNOWLEDGE OF BIOLOGICAL EFFECTS CAUSED BY PRIMARY COSMIC RAYS

During the last few years, successful development of balloon techniques has made possible the limited exposure of biological materials to cosmic radiation. This development, pioneered by Simons and associates (Ref. 21, 22, 23, 24), has resulted in the demonstration of observable biological effects and culminated in making it feasible for man to spend several hours at altitudes near 100,000 feet.

The qualitative evidence, briefly summarized as obtained from balloon flights and studies in cyclotrons and reactors, is as follows: Single cells and unicellular organisms may be killed, and their cell division or proliferation inhibited by single heavily ionizing cosmic ray primaries. The sensitivity of various cells is very different in this respect. We know from the work of Conger and Giles (Ref. 25) that a single alpha particle can cause profound shattering of chromosomes in Tradescantia microspores. Zirkle and Bloom (Ref. 26) have shown that protons are much more effective on the nucleus of newt heart cells in tissue culture than on the cytoplasm. Birge and Sayeg (Ref. 27) have shown that six-times ionized carbon ions can kill individual yeast cells, but will not do so in each instance when they pass through the cell. They obtained some evidence that killing effectiveness of the carbon nuclei is actually diminishing in the most ionizing portions of the track. Eugster (Ref. 28) has demonstrated in balloon experiments that eggs of Artemia salina, a salt crab, can occasionally be killed by a single cosmic ray event. Reverse biochemical mutations can apparently be accelerated by primary cosmic rays as indicated by preliminary work carried out by Stone et al. on Neurospora (Ref. 29). None of these studies have as yet shown conclusively an unexpectedly great efficiency of heavy nuclei to affect cells as compared to quantitative studies with other, better-known radiations. The Relative Biological Effectiveness (RBE) values previously estimated (Ref. 1) still appear to give conservatively low estimates from the point of view of health protection.

For a number of years there has been an interest on the part of meteorobiologists to correlate variations in biological systems with meteorologic phenomena, solar and lunar cycle, etc. The possible influence of cosmic ray showers at ground level with chemical reducing power of bacteria was recently investigated by Tzchaschel et al. (Ref. 49). After prolonged careful observations, some correlation between mean cosmic ray level and reducing ability was found.

A. Tissues

The function of organized multicellular units may be knocked out by single heavily ionizing events. This was first clearly demonstrated by Chase and Post (Ref. 30). They have flown an inbred strain of mice with black hair to high altitude and observed that the hair color changed to white in single, isolated hair follicles exposed to heavy nuclei. Eugster (Ref. 28) designed another technique where an excised piece of skin is flown and then regrafted to the animal for further study.

Analysis of the data by Chase has so far failed to give a definite clue to the nature of the particle needed to cause the hair-color change. Assuming that all particles that ionize heavier than a threshold value can cause the effect, while those ionizing lighter cannot, then the flights in 1954 suggest that a Linear Energy Transfer (LET) of at least 7×10^8 ev g^{-1} cm^2 is needed. The 1955 flights show effect for particles of greater than 3.5×10^9 ev g^{-1} cm^2 LET. These figures were derived by using particle frequency tables prepared by Schaefer (Ref. 31 and 32). One source of possible interpretational error is in the continuing variation of primary intensity and energy distribution near cutoff discussed earlier in this report. This was not directly taken into account. One should apparently monitor the distribution of primary events in each flight. Nevertheless, cosmic ray intensity variations do not seem large enough to explain the discrepancy of the results a year apart, and biological variations of sensitivity dependent on environmental factors (temperature, state of anoxia, state of stress) may well have been involved. The interpretation is also complicated by the fact that obliquely incident particles may cross the skin twice, thus producing greater effect.

Some interesting events were found that allow one to calculate the cross section for hair-color change for certain particles. In a few cases a streak of white hairs resulted, pointing to the passage of a particle (or a narrow bundle of particles) along the surface of the skin. One such streak was 2.9 mm long, and 13 white hairs were found along it.

Now assume that the number of white hairs along a finite segment of Δx of the track is Δn; the number of hair follicles originating in the skin per mm^3 N_h, and the cross section for producing a white hair σ, then

$$\Delta n = \sigma \cdot N_h \cdot \Delta x$$

or

$$\sigma = \frac{\Delta n}{\Delta x} \cdot \frac{1}{N_h}$$

for the above track assuming an average spacing of 120μ between hairs,* we get $\sigma \approx 750\mu^2$; this corresponds to a target area of about 30μ in diameter. The diameter of the hair bulb is about 40μ, and the target area seems somewhat larger than the area occupied by the matrix cells which store the basic pigment granules. Previous work by Chase (Ref. 51) tends to show that active follicles have 6 to 12 dendrite cells which are sources of the melanin granules. Thus it would appear as though it is sufficient for a heavy primary to cross the matrix of pigmented cells any place, not necessarily passing through each individual cell, and inactivate the pigmentary role of 6 to 12 melanogenic cells and more than 30 matrix cells. It is possible that the particle making the particular track was very heavy, and if it was also a very fast particle, the delta rays might have penetrated as far as 100 microns from the track. We know, however, that high energy delta rays are not efficient in causing a change of hair color. Calculations were also made regarding the distribution of secondary X-rays around the track, originating from rearrangement of the primary ionization, but these are absorbed within 10μ from the track, and in fact the high dose portion of the track is only 1 to 2μ wide. It appears, therefore, that some very heavy particles can cause biological effects in tissue at a distance from their ionizing core. Further studies are required to clarify the reason. It is possible that the trauma caused by a particle in the vicinity of the hair follicle will affect the pigment cells, or that the change in hair color results from temporary or permanent impairment of capillary circulation supplying the follicle.

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* Chase, private communication.

Two additional events were found in the balloon experiments on mouse skin. In one case, a cluster of perhaps 30 to 40 hair follicles was affected, and these gave rise to white hair; in another animal many scattered white hairs resulted over the entire animal. The first event seems to be too big for a single particle to have originated it, and the second would necessitate a shower of many heavily ionizing particles. If each follicle were individually irradiated, it would have taken hundreds of electrons to produce the event. Both events may have been caused by very rare cosmic ray phenomena; further studies would be needed to obtain their frequency. The highest energy events in cosmic ray physics are known as Auger showers, which may have as much as 10^{16} ev in their primary. These events are usually observed at ground level, since they cause large showers of particles and X-rays, sometimes over a square mile area. The Auger showers may originate as single particles; they produce a narrow beam of many secondaries when they hit the atmosphere. These in turn produce cascades and eventually end up as large showers. Statistically, these events are so rare that a person flying at high altitude may be exposed to only one per year. It is interesting to speculate that the two unusual events observed by Chase are actually expressions of unusual cosmic ray phenomena. It is, of course, also possible that the unusual patterns of hair-color changes are expressions of biological chain reactions, or variations of sensitivity accentuated by the special environment conditions, or that by chance a high frequency of heavy primaries arrived.

In the field of tissue responses, again a certain amount of work is reported based on ground level observations. In the past, various unsubstantiated claims have been made regarding tissue effects (carcinogenic effect, effect on embryonic state, etc.). Recently Brown et al. (Ref. 50) purport to show an effect of lead-induced showers on the pigmentary system of the Fiddler crab. These authors did not attempt to measure the cosmic ray intensity in their experiments and neglected to duplicate the results by exposing their animals to X-rays.

B. Progress in Heavy Ion Work with Accelerators

Up until recently, the only sources of fast heavy ions were cyclotrons that utilized multiply-charged ions formed close to their ion sources for acceleration (Ref. 33, 34, and 35), and the only place where biological work was carried out with them was Berkeley (Ref. 36).

On 11 April 1957 the first full energy nitrogen beam was obtained from the new Heavy Ion Linear Accelerator (HILAC) at the Radiation Laboratory (Ref. 37). This machine was designed for accelerating multiply-charged ions to an energy of 10 Mev per nucleon, and it is one of two similar accelerators (Ref. 38 and 39); the second one is being built at Yale University. An ion source provides milliampere beams of

ions with charge-to-mass ratio e/m = 0.15; these are accelerated in a Cockroft-Walton machine to 0.07 Mev per nucleon and enter a short linear accelerator. Here their energy reaches one Mev per nucleon and the beam is passed through a very thin layer of gaseous matter where the ions lose electrons so that their charge-to-mass ratio becomes e/m ≈ 0.35. The rest of the acceleration is carried out in a cavity 108 inches in diameter and 50 feet long, that is provided with 68 drift tubes. A photograph of the internal aspect of this cavity is given in figure 32. So far, strong beams of carbon, nitrogen, oxygen, and neon particles have been obtained, and there is some hope for acceleration of other ions up to heavily ionized argon. The machine delivers particles with very uniform energy traveling in a nearly parallel stream. Figure 33 shows two oxygen nuclei coming to rest in nuclear emulsion, and a third oxygen particle which makes a nuclear disintegration. Figure 34 shows similar events in an electron-sensitive nuclear emulsion. These are reproduced by courtesy of Harry H. Heckman. The intensity of the beam is more than ample for biological experimentation - the dose is limited only by efficient cooling of the target and it seems feasible to give as much as 10^9 rad. The beam is pulsed and a single pulse is two millisec in duration, five pulses per second. A sizeable dose can be delivered by a single pulse.

Biophysical experimentation began in 1957, and after initial dose calibrations it will be possible to do both fundamental and applied radiobiological studies. A biological exposure device was designed by Fluke and Birge. A schematic view of such a device is shown in figure 35. It is shown that the beam is first deflected by an "analyzer" magnet, which will assure uniformity in particle momenta, then is passed through a vacuum tube several feet long, before striking the biological exposure device. At the left end of the tube a scattering foil may be employed to spread the narrow beam of the HILAC to a uniform field of approximately 2 cm diameter.

For biological exposures it is desirable to provide a method of selecting the energy of particles; this is taken care of by an absorber wheel. The radiation exposure may be done in vacuum, as would be the case for dried enzymes, viruses, or cells; a thin layer of exposed animal tissue may be irradiated in air through a window. The dose may be measured by measurement of the beam current or in a foil chamber that collects delta rays knocked out from a thin foil.

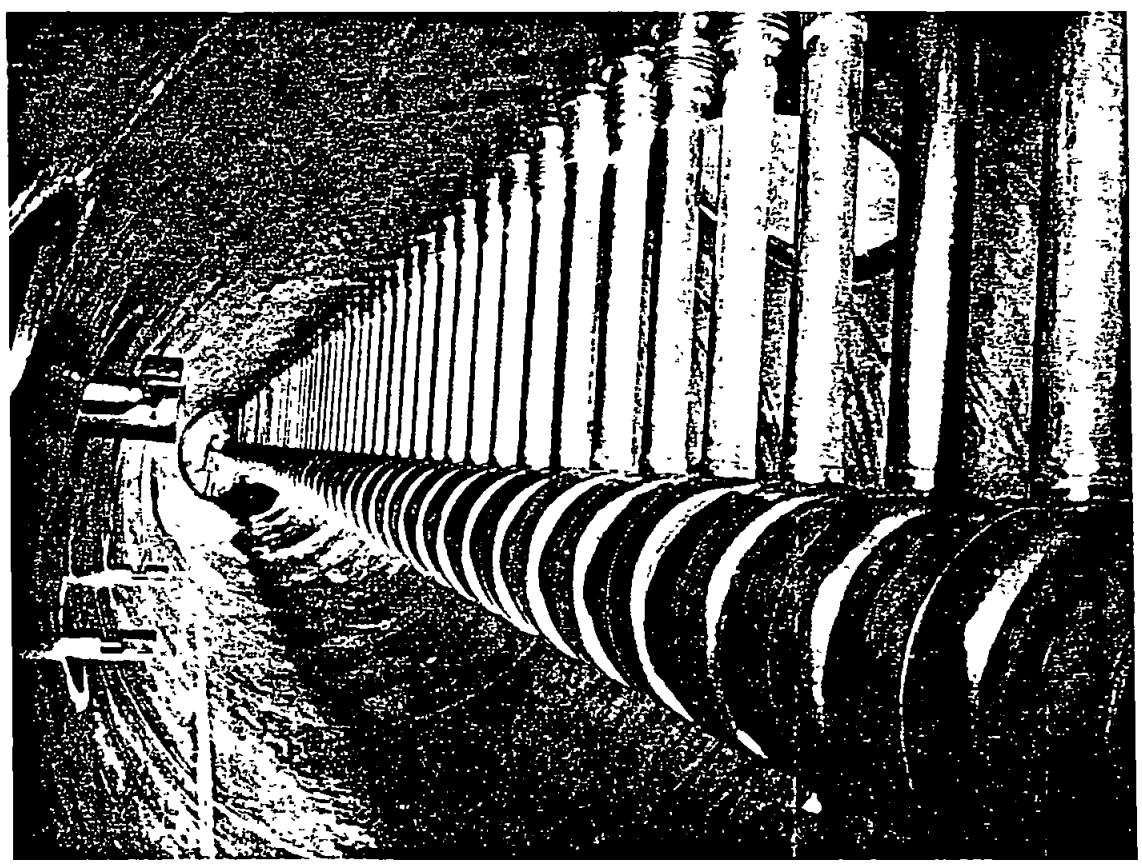

FIGURE 32. Interior of the Main Tank of the Berkeley Heavy Ion Linear Accelerator, Showing the Precise Array of Drift Tubes. For size comparison, note person at opposite end of tank.

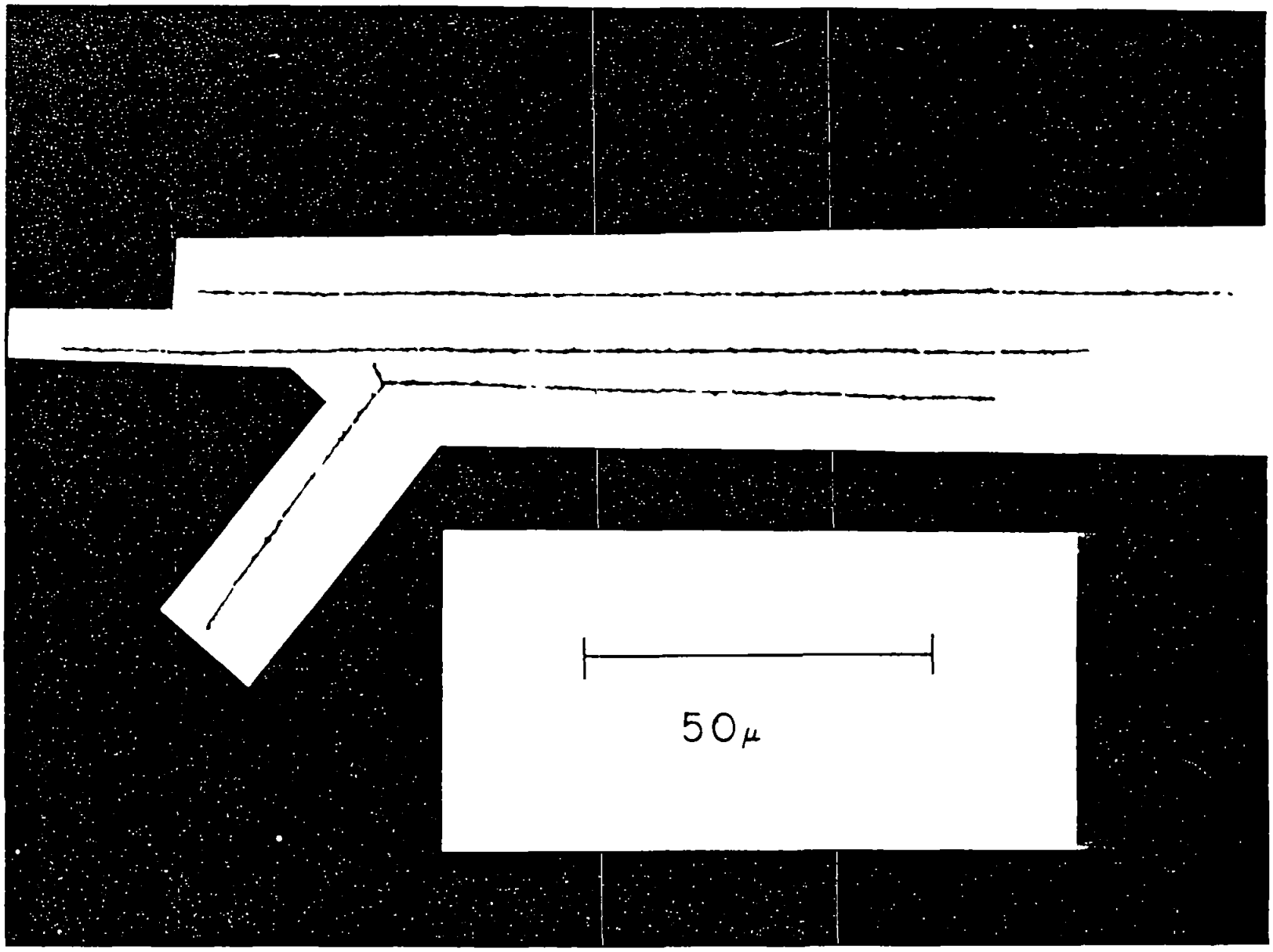

FIGURE 33.

Two Fast Oxygen Nuclei Coming to Rest in Nuclear Emulsion, and a Third One Involved in Nuclear Collision. The particles move from right to left. Reproduced by courtesy of Harry H. Heckman.

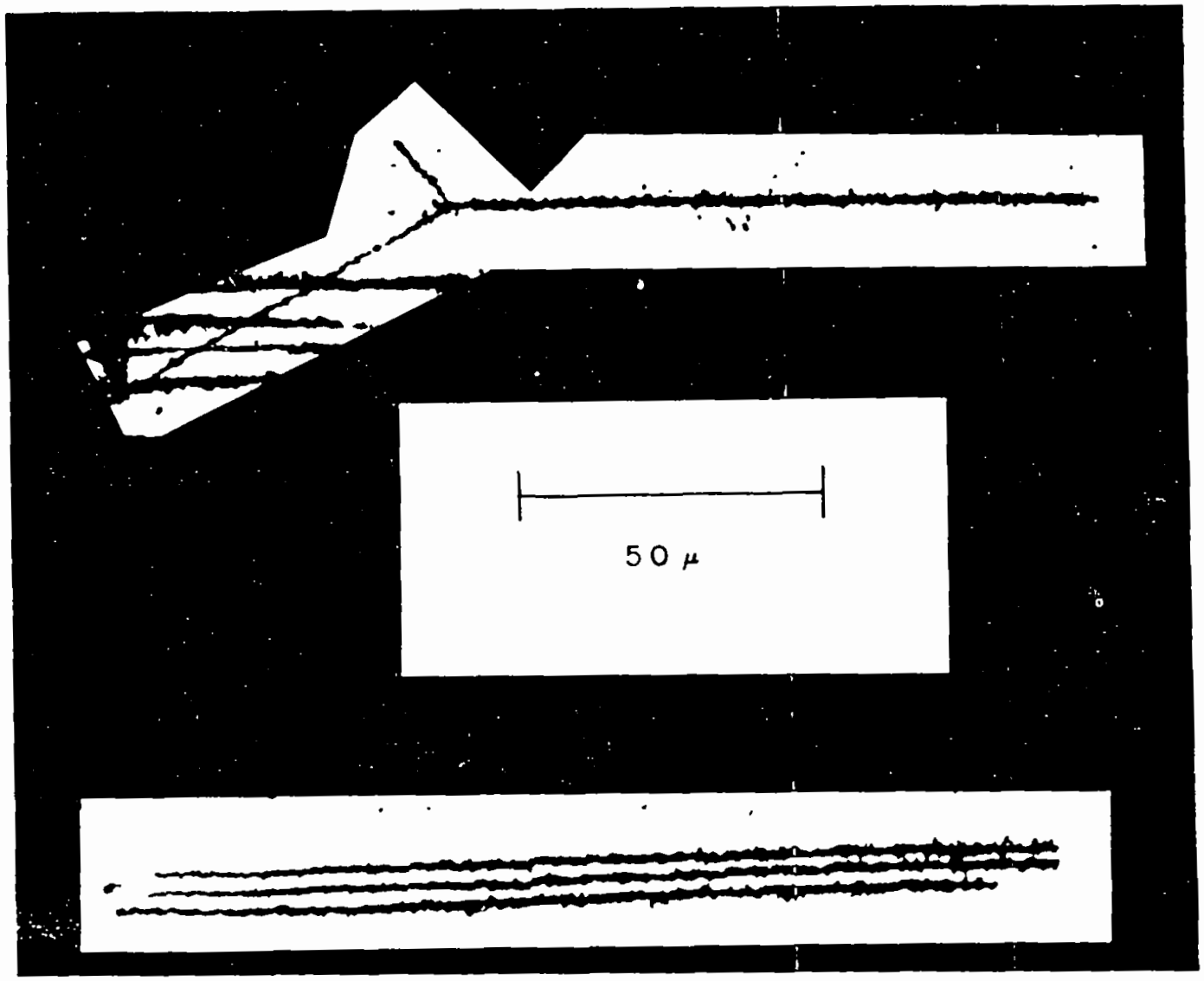

FIGURE 34.

Oxygen Tracks in Electron-Sensitive Emulsion,
Which Shows the Ionization Due to Delta Rays.
Reproduced by courtesy of Harry H. Heckman.

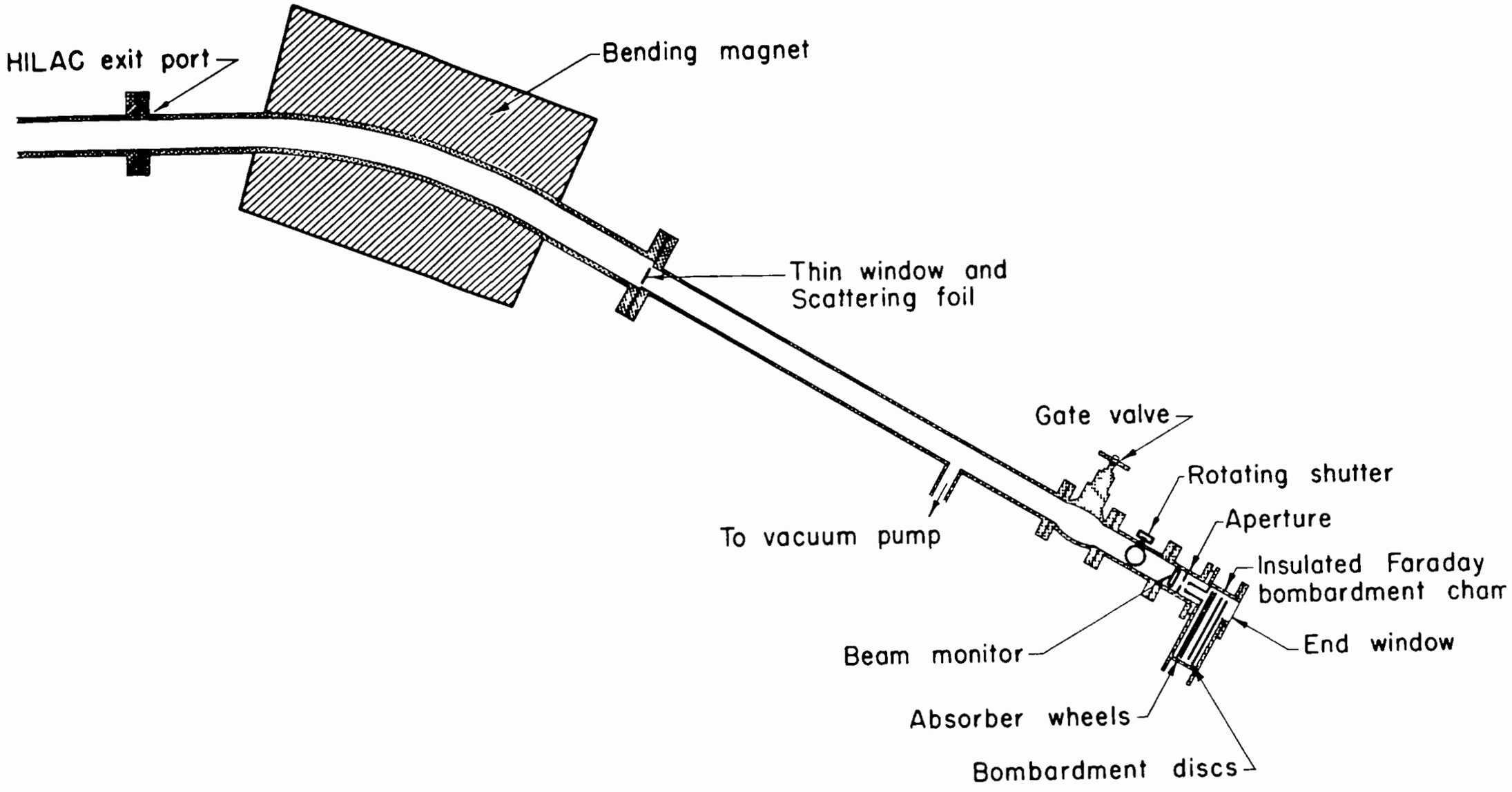

FIGURE 35. General Arrangement for Biological Exposures with Multiply-Charged Ions from the HILAC.

The table below shows the LET values and the approximate depth of penetration of different particles available, as given by Fluke*

Ion	Energy Mev	Initial LET Kev/μ	Total Range mg/cm^2	Useful Range mg/cm^2
$C^{(6+)}$	120	165	57	28
$N^{(7+)}$	140	225	49	25
$O^{(8+)}$	160	295	43	22
$Ne^{(10+)}$	200	460	34	17

The machine is thus suitable for study of surface events in small animals, e.g., on skin, cornea, mesentery, or brain surface. A small bundle of nerve fibers could also be penetrated by any of the available beams.

The successful operation of the HILAC at the sample intensities obtained makes it profitable to think of further extensions of the method. Controlled stripping of electrons from atoms should make it feasible to accelerate nuclei with any atomic number along principles similar to those used at present. Also, acceleration of the ions to much higher energies should be possible. Doubling of the present energy may be reached by adding another section of linear acceleration. Energies of several BEV per nucleon can be reached when one uses a HILAC type machine for injection of particles in a synchrocyclotron. One method for injection has been described (Ref. 40).

C. Biological Work with High Energy Cyclotron Beams

It has been pointed out repeatedly (Ref. 1 and 30) that the hazard of heavily ionizing cosmic rays might lie in part in damage to body cells and tissues which have essential function, low redundancy, and low rate of replacement or recovery from radiation. It is assumed that nerve cells fall in this category, and speculations have been made concerning the existence of foci in the brain which depend on very few

* Private communication.

cells to function. We do know that large parts of the brain lobes can be destroyed or invaded by tumor without great apparent damage to life itself. However, the hypothalamus has small centers that have essential roles in homeostatic regulation; destruction of a single pair of such centers should be considered.

For several years now, the Berkeley group has applied narrow beams of protons and deuterons to the brain and hypothalamus of the rat (Ref. 41), and the effects of pituitary irradiation have been explored in detail (Ref. 42 and 43). The beam diameter can be made as small as about 500 microns. Lesions were only observed, however, when beam diameters larger than 1 or 2 mm were used. The brain has slight movements reflecting the heartbeat and respiration, and these movements tend to increase the irradiated area when exposure is not instantaneous. It is possible to obtain a fairly well defined hypothalamic lesion, like the one shown in figure 36, where there is complete liquifaction of cellular material inside, and no visible damage outside the region. Most of the time, however, the lesions are irregular and their spread follows pathways of circulatory supply. With elapsed time, nerve trunks that leave the irradiated lesion also show progressive degeneration. Physiological malfunction is often present as a result of irradiation, even before histological damage becomes evident. In acute experiments (three months), lesions were obtained only if 8000 rad or more were given, although with refinement of observational techniques one should be able to detect damage at smaller doses. Symptoms observed included diabetes insipidus, impairment of growth and appetite, lowered thyroid iodine uptake, regression of gonads, hyperexcitation, rage, abdominal bleeding, and failure of body temperature control. The damage is in part secondary to radiation damage to the capillary bed. The inner core of heavy primary cosmic ray particles is sufficiently ionizing to produce permanent nerve damage. At present it is believed that many particles have to strike in the same vicinity before the lesion produced becomes large enough to produce permanent observable changes in homeostatic balance.

After only 945 rad to the pituitary region, obesity resulted in the animals over a span of two years. When chronic effects are under study, one obtains changes with relatively small doses (Ref. 43).

Doses of over 1000 rad seem to result in permanent destruction of capillaries and sclerosis of larger blood vessels. The microscopic lesions from heavy primaries, though very small in number, would undoubtedly add to this kind of aging process in the brain.

Studies with high energy protons on animals and humans are being continued at Berkeley. Recently the 200-Mev proton cyclotron of Svedberg in Uppsala, Sweden, was also adapted to localized irradiation studies. Borje Larsson, in collaboration with Leksell, Redsed,

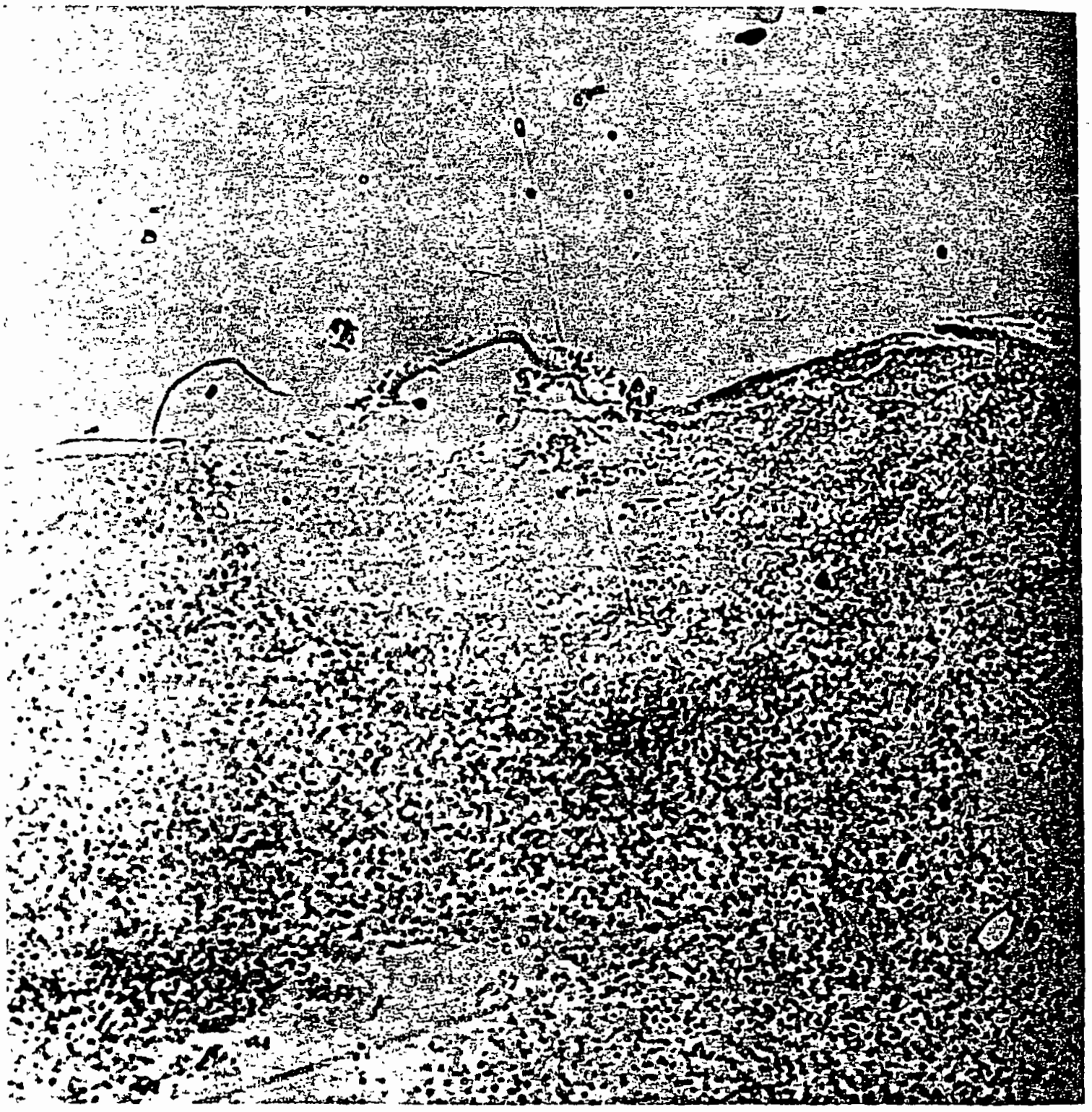

FIGURE 36. Sagittal Section of Rat Hypothalamus in the Region of the Median Eminence, Showing Contours of a Deuteron-Induced Lesion. Dose 16,000 rad. The edge of the lesion, rich in glial cells, follows the contour of the beam, which was 2.4 mm in diameter. The rat was sacrificed 135 days after irradiation. Asur Eosin strain. From unpublished data of the Donner Laboratory group.

and Sourander, is making significant contributions to the problem of radiosensitivity of neural tissue and the localization of instinctive behavior centers in animals.*

D. Radiation Safety in Flying

Since the previous paper (Ref. 1) new recommendations have been issued by the National Bureau of Standards for permissible exposures (Ref. 44). These new standards do not change the validity of the previous calculations. Thus flying activities up to the top of the atmosphere remain within the permissible limit. Only high above the poles, in certain years, should one expect to observe a higher dose.

A new estimate is presented here for travel conditions in a space ship traveling for long periods of time unshielded by the magnetic field of the earth (for practical reasons higher up than one earth radius). In the first part of this paper, the 24-hour daily mean dose is quoted as 25 millirad. Variations may exceed 100 percent. If one assumes a relative effectiveness of seven for primary cosmic rays (Ref. 1), an aviator might be exposed to 1.2 rem per week. This is four times the weekly permissible dose, but an individual may spend up to one-fourth of a year or twelve weeks in flight per year if he has no other significant exposure during the year.

It seems likely that long flights into space will cause exposures in excess to our presently accepted permissible doses. The possible effects of radiation, expressed as average, would still be small for the individual. For considerations of eventual individual or population damage, one might well take the statistical view suggested more than 100 years ago by Gomperz, and recently considered in detail by Jones (Ref. 45). Briefly, the physiologic age of the individual is characterized by certain figures representing his chance to die, or his chance to get some disease. The probability of death is a function increasing exponentially through most of a man's lifetime with a doubling time of about eight years; but populations from different countries, or exposed to different environmental conditions, are represented by different death probability regression lines.

The individuals of different actual age have identical physiological age if they belong to populations that have the same rate of death. Assessment of animal data and analysis of Hiroshima survivors led Jones to postulate that the effect of a dose of radiation is to cause immediate aging; one roentgen is supposed to increase physiological age by about 5 to 10 days. A single dose is not supposed to change the doubling time of death rate, but the probability of various

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* The last problem on a USAF contract.

diseases, particularly cancer and leukemia, increases in step with the aging. Leukemia incidence and mutation rate are supposed to double after a dose of 25-50 r, but our ignorance in these fields is so great that we have no reliable measurements at all at doses below 50 r; it is possible that some recovery mechanism exists which makes man more resistant to low dose rates. Blair (Ref. 46) found recovery in animals exposed to X-ray, but claims much less recovery for fast neutrons, and we do not know whether the effect of very heavy nuclei is prone to recovery or the damage is permanent.

Because of the large variety of cosmic ray events, the statistical approach should prevail for consideration of the hazard. Thus, if a thousand people fly simultaneously on a given day, three of these may have an Auger shower passed through their bodies, while the others would not be exposed to this event at all.

A statistical approach would be of value in determining the physiological age of aviators, since this method would bring out the areas of greatest hazard. One environmental factor that actually is responsible for definite physiological changes is reduced oxygen tension. Not only professional pilots, but a large segment of the population is exposed to this from time to time. Yet the author cannot find any data on physiological age measurements in animals during continuous or intermittent anoxia. Even this factor interferes with radiation effect, since X-ray irradiated animals live longer if they are anoxic at the time of exposure.

In balloon flights of the near future, men plan to ascend to 100,000 feet elevation, and will be exposed to some heavy primaries. The effects should be so minute that they may escape detection. However, if our knowledge of X-rays can be carried to this field (Ref. 47), then it would seem that a dark adapted person should be able to see very heavily ionizing single tracks as a small light flash, since they would pass through several retinal receptors, enough to correspond to a visual object of greater than one foot angular aperture. If a track travels within the plane of the retina, several rods and cones may be inactivated, producing a microscopic retinal lesion that may be detectable by visual field measurements. The statistics of the situation are comparable to Chase's skin experiments, except that the rods are smaller (3μ diameter) and are closer than hair follicles (a few microns apart).

IV. CONCLUSIONS

A. Cosmic ray intensity near the earth, but away from its magnetic field, averages 3.5×10^{-3} erg cm^{-2} sec^{-1} $ster^{-1}$, corresponding to a dose of about 25 millirad per 24-hour day. These figures are uncertain by about 100 percent.

B. Most primary cosmic rays originate in our galaxy and reach the earth isotropically. About 10 percent of the primary rays originate from the sun.

C. Long-term changes in cosmic ray intensity depend on galactic events. The birth of radio stars may considerably modify cosmic ray intensity.

D. Short-term changes in cosmic ray intensity correlate with solar activity. In part, the ionized magnetic clouds originating from the sun modulate the intensity of galactic rays arriving on the earth; in part, solar primaries are accelerated and add to cosmic ray intensity.

E. The most spectacular variations in the primaries follow large solar flares by about an hour. The primary component may increase by as much as thirty-fold. Smaller sunspots are followed by minor increases.

F. Following solar flares by a day, there is a small percent decrease in cosmic ray intensity correlated with atmospheric radio and magnetic disturbances.

G. There is an important variation in primary, particularly low energy, cosmic rays over an 11-year cycle. The variation in space (away from earth) is at least 2.4-fold, and is high when sunspot activity is low.

H. Smaller variations also exist. Direct high altitude measurement of primary particles shows over 20 percent variation of intensity within a few hours.

I. Because of the variations in time and space in cosmic ray spectrum and intensity, it is difficult to obtain quantitative measurements of biological effects of cosmic rays correlated with their energy spectrum. At present, such tests have chiefly qualitative significance.

J. It is established that single primaries near the top of the atmosphere can kill single cells and unicellular organisms, but do not always do so. They also cause mutations.

K. Significant effects of primary cosmic ray particles have been shown on hair follicles. Some of these effects seem to appear as much as 15 microns away from the track of the particles; others are much too large to be caused by direct ionizing interaction with single primaries. The cause may be unusually large cosmic ray events or biological chain reactions.

L. A new Heavy Ion Linear Accelerator has been completed in Berkeley, yielding accelerated nuclei from C^{6+} to Ne^{10+} with 10 Mev energy per nucleon.

M. Biophysical experiments have been initiated to provide quantitative information of radiation effects over a 200-fold range in linear energy transfer on single cells and thin layers of tissues.

N. There are no theoretical obstacles to accelerating heavy nuclei to energies of several BEV per nucleon.

O. Flights near the top of the atmosphere may be carried out frequently without obtaining more dose than the permissible weekly limit suggested by the National Bureau of Standards.

P. In space, away from the earth's shielding magnetic field, a yearly permissible dose may be obtained in about 12 weeks of flying. Direct measurements of spatial cosmic ray intensity are needed.

Q. Proton and deuteron irradiation of essential hypothalamic centers indicates that several thousand rad dose over a cubic millimeter area is needed to produce lesions with significant deleterious effect. Obesity and permanent sclerotic impairment of circulation may result from smaller doses or more localized rays.

R. For full evaluation of radiation effects on aging of pilots, more corollary information is needed. We do not as yet know the effect of partial anoxia on aging or the effect of other stress that involves the pituitary-adrenal axis.

S. Dark adapted flyers at very high altitude may be able to observe a small light flash when a heavy primary crosses their retinas, and some slight permanent damage to their visual field might result.

REFERENCES

1. Tobias, Cornelius A., "Radiation Hazards in High Altitude Aviation," J. Aviation Med., 23:345 (1952).

2. Kaplon, M. F., B. Peters, H. L. Reynolds, and D. M. Ritson, "The Energy Spectrum of Primary Cosmic Radiation," Physical Review, 85:295 (1952).

3. Ellis, R. A., M. B. Gottlieb, and J. A. Van Allen, "Low Momentum End of the Spectrum of Heavy Primary Cosmic Rays," State University of Iowa 54-3.

4. Fermi, E., "On the Origin of Cosmic Radiation," Physical Review, 75:1169 (1949).

5. DeHoffmann, F., and E. Teller, "Magneto Hydrodynamic Shocks," Physical Review, 80:692 (1951).

6. Unsold, Albrecht, "Uber den Ursprung der Radiofrequenzstrahlung und der Ultrastrahlung in der Milchstrasse," Zeitschrift für Astrophysik, 26:176 (1949).

7. Morrison, P., S. Albert, and B. Rossi, "Origin of Cosmic Rays," Physical Review, 94:440 (1954).

8. Rossi, B., "Lectures on the Origin of Cosmic Rays," Nuovo Cimento, Ser. 10-2, p. 275 (1955).

9. Elliott, H., Progress in Cosmic Ray Physics, Chapter VIII, J. G. Wilson, ed., Amsterdam, 1952.

10. Brode, R. B., and A. Goodwin, Jr., "Extraordinary Increase of Cosmic Radiation of February 23, 1956," Physical Review, 103:377 (1956).

11. Lockwood, J. A., H. E. Yingst, A. R. Calawa, and G. Sarmaniote, "Cosmic Ray Neutron Intensity Increase with Solar Flare of February 23, 1956," Physical Review, 103:247 (1956).

12. Firor, J., "Cosmic Ray Intensity Time Variations and Their Origin, IV," Physical Review, 94:1017 (1954).

13. Strughold, H., "The Ecosphere of the Sun," J. Aviation Med., 26:323 (1955).

14. Simpson, J. A., W. Fonger, and S. B. Treiman, "Cosmic Ray Intensity Variations and Their Origin, I," Physical Review, 90:934 (1953).

15. Koshiba, M., and M. Schein, "Time Variation of Primary Heavy Nuclei in Cosmic Radiation," Physical Review, 103:1820 (1956).

16. Morrison, P., "Solar Origin of Cosmic Ray Time Variations," Physical Review, 101:1397 (1956).

17. Forbush, S. E., "World-wide Cosmic-ray Variations, 1937-1952," J. of Geophys. Res., 59:525 (1954).

18. Meyer, P., and J. A. Simpson, "Changes in Amplitude of the Cosmic Ray Twenty-seven Day Intensity Variation with Solar Activity," Physical Review, 96:1085 (1954).

19. Neher, H. V., "Low Energy Primary Cosmic Ray Particles in 1954," Physical Review, 103:228 (1956).

20. Teller, E., "Theory of Origin of Cosmic Rays," Reports Progr. Phys., 17:154 (1954).

21. Simons, D. G., and C. H. Steinmetz, "The 1954 Aeromedical Field Laboratory Balloon Flights," J. Aviation Med., 27:100 (1954).

22. Simons, D. G., "Methods and Results of One Year of Balloon Flights with Biological Specimens," J. Aviation Med., 25:380 (1954).

23. Simons, D. G., "Stratosphere Balloon Techniques for Exposing Living Specimens to Primary Cosmic Ray Particles," HADC-TR-54-16, 1954.

24. Stearns, C. R., "Flight Series in Minnesota, Summer, 1955," Final Report, Contract No. AF26(600)-632.

25. Conger, A. D., and N. H. Giles, Jr., "The Cytogenetic Effect of Slow Neutrons," Genetics, 35:397 (1950).

26. Zirkle, Raymond E., "Cellular Changes Following Irradiation," in Cellular Aspects of Basic Mechanisms in Radiobiology, H. Patt and E. L. Powers, ed., National Academy of Science Publication NRC 450, p. 1, 1956.

27. Sayeg, J. A., "The Effect of Highly Ionizing Radiations on Cell Survival," University of California Radiation Laboratory Report UCRL 2293, 1954.

28. Eugster, J., "Method of Demonstrating the Biological Effectiveness of Cosmic Radiation at High Altitudes," J. Aviation Med., 24: 222 (1953).

29. Stone, Wilson S., Private Communication, The Genetics Foundation, University of Texas, Austin, Texas.

30. Chase, H. B., and J. S. Post, "Damage and Repair in Mammalian Tissues Exposed to Cosmic Ray Heavy Nuclei," J. Aviation Med., 27:533 (1956).

31. Schaefer, H. J., "Graphs and Tables for the Hit Frequencies for Small Specimens," U. S. Naval School of Aviation Medicine, Project Report No. NM 001 059.13.08 (1954).

32. Schaefer, H. J., "Hit Frequencies for Spherical Targets of Two to Five cm Diameter (Small Mammals)," U. S. Naval School of Aviation Medicine, Project Report No. NM 001 059.13.09 (1954).

33. Rossi, G. B., W. B. Jones, J. M. Hollander, and J. G. Hamilton, "Acceleration of Nitrogen 14 (+6) Ions in a 60-Inch Cyclotron," Physical Review, 93:256 (1954).

34. Walker, D., and J. H. Fremlin, "Acceleration of Heavy Ions to High Energies," Nature, 171:189 (1953).

35. Atterling, Hugo, "Acceleration of Heavy Ions in the 225 cm Cyclotron at the Nobel Institute of Physics," Arkiv. F. Fysik, 7:503 (1954).

36. Sayeg, J., and A. Birge, "The Relative Biological Effectiveness of Various Highly Ionizing Radiations on Yeast Cells," (A) Rad. Res. 1, No. 6 (December 1954).

37. University of California Radiation Laboratory Report UCRL 3782, p. 55, 13 May 1957.

38. Beringer, R., R. L. Gluckstern, M. S. Malkin, E. L. Hubbard, L. Smith, and C. Van Atta, "Linear Accelerator for Heavy Ions," University of California Radiation Laboratory Report, UCRL 2796, 29 November 1954.

39. Wells, D., "Linear Accelerator for Heavy Ions," University of California Radiation Laboratory Report, UCRL 3365, 27 March 1956.

40. Tobias, C. A., Method and Apparatus for Nuclear Particle Acceleration, U. S. Patent No. 2,789,221, 1957.

41. Anderson, A., J. Garcia, J. Henry, C. Riggs, J. E. Roberts, Bo Thorell, and C. A. Tobias, "Pituitary and Hypothalamic Lesions Produced by High Energy Deuterons and Protons," Annual Meeting Rad. Res. Soc., April 1957.

42. Tobias, C., D. Van Dyke, M. E. Simpson, H. O. Anger, R. L. Huff, and A. A. Koneff, "Irradiation of the Pituitary of the Rat with High Energy Deuterons," Am. J. Roentgenol., Rad. Ther. and Nuc. Med, 72:1-21 (1954).

43. Simpson, M. E., D. C. Van Dyke, A. A. Koneff, and C. A. Tobias, "Results of Pituitary Irradiation on Structure and Function of Endocrine Glands," in preparation.

44. NBS Handbook 59, 1954, and Insert to Accompany Handbook 59, 1957, U. S. Government Printing Office, Washington 25, D. C.

45. Jones, H. B., "A Special Consideration of the Aging Process, Disease and Life Expectancy," Advances of Biol. and Med. Phys., J. H. Lawrence and C. A. Tobias, ed., Volume IV, p. 281, 1956.

46. Blair, H. A., "A Formulation of the Injury, Life Span, Dose Relations for Ionizing Radiations," University of Rochester AEC Report UR-206, 1953.

47. Lipetz, Leo, "An Electrophysiological Study of Some Properties of the Vertibrate Retina," Thesis, University of California, University of California Radiation Laboratory Report, UCRL 2056, 1953.

48. Danielson, R. E., P. S. Freier, J. E. Naugle, and E. P. Ney, "Heavy Primary Cosmic Radiation at the Equator," Physical Review, 103:1075 (1956).

49. Tzchaschel, R., H. Knoll, and F. Berger, "Untersuchungen uber den Einfluss der Kosmischen Ultrastrahlung auf Mikroörganismen vom Standpunkt der Meteorobiologie," Zentralbl. f. Bakteriol., Abt 1, 161, 99 (1954).

50. Brown, F. A. Jr., M. F. Bennett, and C. L. Ralph, "Apparent Reversible Influence of Cosmic Ray Induced Showers Upon a Biological System," Proc. Soc. Exp. Biol., 89:332 (1955).

51. Chase, H. B., "Number of Entities Inactivated by X-Rays in Greying Hair," Science, 113:714 (1951).

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